

## **Historic, Archive Document**

Do not assume content reflects current scientific knowledge, policies, or practices.



Reserve  
aQK495  
T35D45  
1991

Saltcedar, An Exotic Weed of Western North American Riparian Areas:  
A Review of Its Taxonomy, Biology, Harmful and Beneficial Values, and  
Its Potential for Biological Control

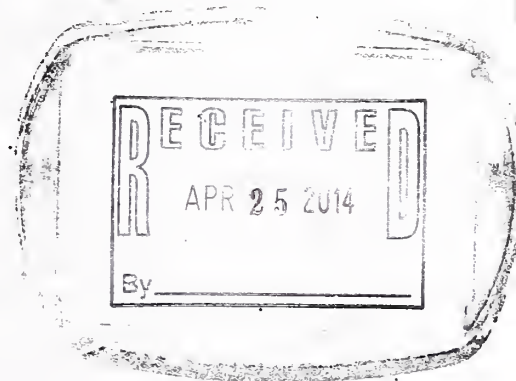
Submitted by C. Jack DeLoach  
Grassland, Soil and Water Research Laboratory  
U.S. Department of Agriculture  
Agricultural Research Service  
808 East Blackland Road  
Temple, Texas 76502

January 1991

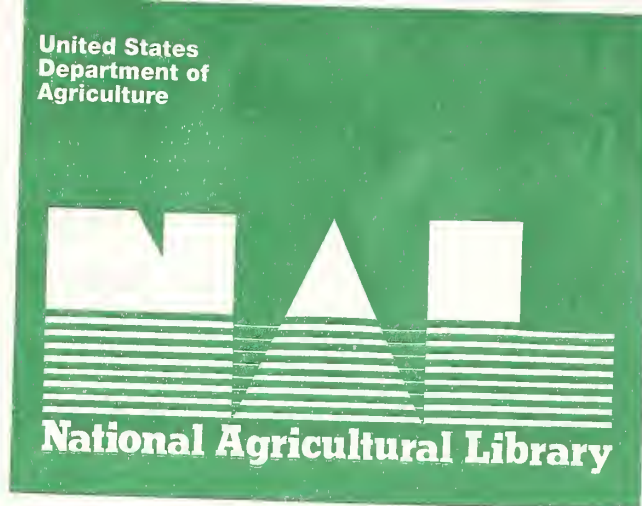
FINAL REPORT

(Volume 1 of 2)

In fulfillment of  
U.S. Bureau of Reclamation  
Contract No. 7-AG-30-04930



USDA National Agricultural Library  
NAL Building  
10301 Baltimore Blvd.  
Beltsville, MD 20705-2351



LIST	.....	v
LIST	.....	xi
PREF	.....	xiv
I. EXEC	.....	1
II. INTI	.....	9
III. TAXONOMY OF SALTCEDEAR	.....	11
IV. SPREAD AND ABUNDANCE OF SALTCEDEAR IN THE U.S.	.....	22
V. BIOLOGY AND ECOLOGY	.....	26
A. Growth Form	.....	26
B. Flowers	.....	28
C. Seeds	.....	29
D. Germination and Establishment	.....	29
E. Leaves	.....	31
F. Roots	.....	32
G. Inundation and Desiccation Stress	.....	34
H. Salt	.....	35
I. Secondary Chemical Compounds	.....	36
VI. DISPLACEMENT OF NATIVE VEGETATION	.....	37
A. Historical Perspective and Present Status	.....	37
1. Lower Colorado River	.....	38
2. Gila River	.....	43
3. Rio Grande	.....	46
4. Brazos River, TX	.....	47
5. Other Regions	.....	48
B. Causes of Riparian Habitat Degradation	.....	48
1. Livestock Overgrazing	.....	52
2. Clearing for Agriculture	.....	54
3. Cutting for Firewood, Charcoal, Construction, etc.	.....	55
4. Dams for Flood Control and Irrigation	.....	56
5. Urbanization, Housing Developments and Recreation, etc.	.....	58
6. Pumping Groundwater	.....	59
7. Phreatophyte Control and Channelization	.....	59
8. Fire	.....	61
9. Exotic Plant Invasions	.....	62
C. Effects of Habitat Degradation on Wildlife	.....	62
D. Prevention of Habitat Degradation and Reclamation of Degraded Areas	.....	65
1. Land Acquisition for Wildlife Habitat	.....	65

2. Revegetation of Saltcedar-cleared Riparian Areas .....	67
a. Examples of revegetation projects .....	68
b. Effects of wildlife enhancement .....	74
c. Factors influencing success .....	75
1. Species of plants used .....	75
2. Depth to groundwater .....	77
3. Soil salinity .....	78
4. Soil type .....	79
5. Irrigation .....	79
6. Damage from weeds, insects, wildlife and livestock .....	80
7. Summary - Criteria for success .....	80
d. Monitoring .....	82
e. Costs of revegetation .....	82
3. Management of Riparian Areas within Public Lands .....	84
4. Mitigation .....	85
5. Control of Harmful Exotic Plant Invaders .....	85
E. Effects of Saltcedar in Parks and Other Protected Areas ...	87
1. Tiernan Survey .....	87
3. Tucson Symposium .....	91
2. Brown Survey .....	93
F. Impact of Biological Control on the Riparian Plant Community .....	95
G. Conclusions .....	98
VII. EFFECTS OF SALT CEDAR ON WILDLIFE .....	101
A. Non-Game Birds .....	101
1. Value of Riparian vs. Other Areas .....	101
2. Birds of the Lower Colorado River, Arizona and California .....	103
3. The Middle Rio Grande River Valley .....	113
4. The Middle Pecos River Valley .....	117
5. Sonora, Mexico .....	125
6. Comparisons of Different River Valleys .....	126
B. Terrestrial Vertebrates .....	127
1. Small Mammals .....	127
2. Reptiles and Amphibians .....	130
C. Damage Caused by Saltcedar to Non-consumptive Wildlife Use ("Bird Watching" etc.) .....	132
D. Game Birds - The White-winged Dove .....	141
1. Taxonomy and Distribution .....	142
2. Habitat Selection - Eastern Area .....	145
3. Habitat Selection - Western and Trans-Pecos Texas Areas .....	146
4. Habitat Selection - Northwestern Mexico .....	155
5. Migration and Annual Cycle .....	157
6. Nesting .....	160
7. Feeding .....	162

8. Mortality and Natural Enemies .....	164
9. Populations and Hunting - Eastern Area .....	167
a. Methods of estimating population and hunting .....	167
b. Populations and hunting - Eastern area .....	169
10. Populations and Hunting - Western Area .....	173
11. Economic and Social Characteristics of Hunters and Hunting in Texas and Mexico .....	178
E. Game Birds - Mourning Dove .....	184
F. Game Birds - Gambel's Quail .....	191
G. Other Game Animals and Birds .....	195
H. Fishes .....	199
I. Drinking Water for Wildlife .....	201
J. Impacts of Biological Control on Wildlife .....	201
1. White-winged and Mourning Dove Hunting .....	202
2. Wildlife Ecological Values .....	203
VIII. USE OF WATER BY SALT CEDAR .....	206
A. Introduction .....	206
1. Historical Perspective .....	206
2. Politico-Administrative Agreements .....	207
a. Lower Colorado River Basin .....	207
b. Pecos River Basin .....	207
c. Research and control planning and coordination ....	208
B. Methodology of Measuring Water Usage by Phreatophytic Plants .....	209
C. Measurements in Lysimeter or Evapotranspiration Tanks ....	212
1. Early Studies in California .....	214
2. Pecos River near Carlsbad, NM .....	214
3. Gila River near Safford, AZ .....	215
4. Gila River near Buckeye, AZ .....	221
a. Facilities .....	221
b. Water usage .....	222
c. Effects of salinity on water usage .....	222
d. Effects of plant density .....	226
e. Diurnal and seasonal fluctuations .....	227
5. Rio Grande near Bernardo, NM .....	229
a. Early studies .....	229
b. Large lysimeter studies: 1960's .....	230
D. Transpiration Wells .....	236
E. Inflow-Outflow Method .....	239
F. Other Methods of Measurement .....	241
1. Seepage-run .....	241
2. Slope-seepage .....	242
3. Chloride-increase .....	243
G. Evapotranspiration Tent Method .....	243
H. Empirical Equations .....	245

I. Micrometeorological Methods .....	247
1. Vapor-flow Methods .....	248
a. Atmospheric-water-balance method .....	248
b. Eddy-correlation method .....	248
c. Bulk aerodynamic (or mass-transfer) method .....	249
2. Energy-budget (or Energy-balance) Method .....	249
a. Studies by van Hylckama .....	250
b. Studies by Gay and coworkers .....	253
J. Water Stress - Diurnal Pattern of Usage .....	260
K. Water Usage Before and After Clearing Phreatophytes .....	264
1. Gila River Phreatophyte Project, San Carlos, AZ .....	264
2. Pecos River Studies.....	269
3. Other Studies .....	272
L. Discussion, Economics, and Effects of Biological Control on Water Usage .....	274
IX. SEDIMENTATION, FLOODING AND SOIL SALINITY .....	283
A. Sedimentation and Flooding .....	283
B. Economic Effects of Saltcedar Control on Flooding .....	286
C. Economic Effects of Saltcedar Control on Sedimentation ....	288
D. Soil Salinity .....	289
X. LIVESTOCK FORAGE: COMPETITION FROM SALT CEDAR .....	291
XI. OTHER HARMFUL VALUES .....	295
XII. VALUE FOR HONEYBEES .....	296
XIII. VALUE OF SALT CEDAR FOR ORNAMENTALS .....	306
A. In Texas .....	306
B. In Arizona and Neighboring States .....	308
XIV. WINDBREAKS, SOIL STABILIZATION AND OTHER USES .....	313
XV. USAGE IN MEXICO .....	315
XVI. NATURAL ENEMIES OF SALT CEDAR .....	319
A. In North America .....	319
B. In Other Areas of the World .....	321
1. In Israel, Turkey, Iran and India .....	321
2. In Pakistan .....	327
XVII. NON-BIOLOGICAL CONTROLS .....	338
A. Herbicidal Controls .....	339
1. Herbicides that Can Be Used to Control Saltcedar .....	339
2. Herbicides Previously Used but Now Prohibited .....	347
3. Past Experience in Herbicidal Control of Saltcedar .....	348

B.	Non-Chemical Controls .....	352
1.	Mowing and Chaining .....	352
2.	Root Plowing .....	353
3.	Combination Mechanical and Chemical Controls .....	353
4.	Burning .....	353
5.	Desiccation .....	354
6.	Inundation .....	355
C.	Cost of Controls .....	355
D.	Conclusions .....	356
XVIII.	BIOLOGICAL CONTROL .....	360
A.	Philosophy and History .....	360
B.	Potential for Biological Control of Saltcedar .....	363
C.	Procedures for Implementing Biological Control of Saltcedar .....	364
XIX.	ECONOMIC ANALYSIS .....	367
A.	Economic Account .....	368
B.	Environmental Account .....	369
C.	Social Well-being Account .....	373
D.	Summary of Accounts .....	378
XX.	SUMMARY .....	382
XXI.	LITERATURE CITED .....	409

## LIST OF TABLES

<u>Table no.</u>	<u>Table title</u>	<u>Page no.</u>
1	Vegetative composition of various riparian areas of which detailed measurements have been made	41
2	Classification of vegetative along the Lower Colorado River from Davis Dam to the U.S.-Mexican border	42
3	Vegetation of the Brazos River and major tributaries in northwestern Texas	49
4	Changes in vegetative composition of the floodplain of the Brazos River, TX, 1940-1969	50
5	Land acquired for wildlife habitat in Texas	66
6	Plantings, results and costs of 17 revegetation projects along the Lower Colorado River	71
7	Costs of revegetation of two representative sites on the Lower Colorado River	83
8	Total areas of riparian vegetation along the Colorado River, AZ and CA, from Davis Dam to the Mexican border	106
9	Comparison of total densities (number per 40 ha) and number of species of birds in 4 plant community types in the Lower Colorado River Valley, December 1975-November 1976	108
10	Patterns of vegetation use by avian groups on the Lower Colorado River	109
11	Species composition of the plant communities on the Rio Grande of western Texas	114
12	Habitat breadths of birds in the Rio Grande Valley, NM	116
13	Pecos River Valley community and structural types	118
14	Mean tree and shrub counts (number per 0.23 ha) for each community/structural type	119
15	Number of species of birds in 14 community/structural types of riparian vegetation by seasons, in the Middle Pecos River Valley, September 1979 to May 1981	122

<u>Table no.</u>	<u>Table title</u>	<u>Page no.</u>
16	Density of birds in 14 community/structural types in the Middle Pecos River riparian area by seasons, September 1979 to May 1981	123
17	Numbers of bird species showing clear preference and mean population of all birds per unit area for different plant communities on three western rivers	127
18	Habitat preference of rodents in the Lower Colorado River Valley, 1974-1979	129
19	Habitat preference for rodents in the Rio Grande Valley of western Texas	129
20	Lizard densities along the Colorado River in Grand Canyon, summer 1984	131
21	Calculation of the value of non-consumptive use of wildlife (observing, feeding, photographing) in riparian areas	134
22	Expenditures for fishing, hunting and non-consumptive usage of wildlife in the U.S., 1985	135
23	Consumptive usage (hunting and fishing): number of participants, days of activity, and expenditures in 1985	136
24	Non-consumptive usage (hunting and fishing): number of participants, days of activity, and expenditures in 1985	137
25	Allocation of primary non-consumptive usage of wildlife to non-residential or residential usage	138
26	Breeding density estimates for various habitat types, Arizona, 1963	147
27	Habitat types used by the white winged dove in Arizona	149
28	Density of the whitewinged dove from May through September in various community/structural vegetational types in the Lower Colorado River Valley, 1975-77	151
29	Reproduction and mortality of the white-winged dove in three riparian communities on the Lower Colorado River	151

<u>Table no.</u>	<u>Table title</u>	<u>Page no.</u>
30	Habitat preference for nesting doves in the Buckeye-Arlington area of the Gila River Valley, AZ	152
31	Populations of mourning dove and white-winged dove on the Gila River from Safford to San Carlos, AZ, summer 1966	153
32	Densities of the white-winged dove along the Lower Colorado River	154
33	Comparison of self-administered mail survey with aerial survey of hunter cars for estimating dove hunting in the Lower Rio Grande Valley, Texas	168
34	White-winged dove breeding populations, percent nesting in citrus (the remainder in native brush or in cities), and harvest by hunters in the Lower Rio Grande Valley or the entire state of Texas	170
35	White-winged dove harvest in Arizona	176
36	Dove hunting in the Lower Rio Grande River, Texas, and in Mexico during 1975	181
37	Average numbers of doves and quail per 100 A in three plant communities in the Lower Colorado River	187
38	Density of the mourning dove in various community/structural types in the Lower Colorado River Valley from May through September 1974-1977	188
39	Density (number per 100 acres) of mourning doves in different plant community-structural types in the middle Pecos River Basin, NM and TX	189
40	Harvest of mourning doves in the Southwest during 1972-73	190
41	Food selection in the field of Gambel's quail in the Lower Colorado River Valley	195
42	Habitat preference and harvest of other game animals	197
43	Waterfowl and other game bird populations and harvest in Arizona	200

<u>Table no.</u>	<u>Table title</u>	<u>Page no.</u>
44	Economic losses to white-winged dove hunting expected from biological control of saltcedar	203
45	Economic losses to mourning dove hunting expected from biological control of saltcedar	204
46	Total water usage by phreatophytes on the Gila River, AZ, based on six methods of calculation	217
47	Water use for selected depths and densities, Glenbar tanks	220
48	Evapotranspiration in cm and (ft) from 30x30 ft lysimeters planted to saltcedar at Buckeye, AZ, 1965	223
49	Twig growth of saltcedar April to June 1966	227
50	Consumptive use of water by saltcedar at Bernardo, NM	231
51	Evapotranspiration of saltcedar at Bernardo, NM, in 1977	258
52	Evapotranspiration (inches/year) as calculated by 4 empirical equations before and after clearing phreatophytes from the floodplain along a 24-mile reach of the Gila River, AZ (rainfall excluded)	268
53	Annual water use in the Pecos River floodplain (estimated range)	270
54	Summary of studies in elevation zone below 4,300 ft. with estimate of evapotranspiration per acre of flood plain	273
55	Projected damage caused by flooding and benefits from biological control of saltcedar on two river systems	287
56	Costs of increased sedimentation of reservoirs resulting from projected 50% or 90% control of saltcedar	289
57	Honey and beeswax production in the southwestern United States	296
58	Contribution of various plants to the annual pollen harvest of honeybees at 10 different apiaries within a 35-mile radius of Tucson	298

<u>Table no.</u>	<u>Table title</u>	<u>Page no.</u>
59	The top ten bee plants as selected by 25 Arizona beekeepers in a survey designed to determine those plants best suited for honey production and for colony maintenance	302
60	Production and value of honeybee products and amount contributed by <u>Tamarix</u>	303
61	Number and value of <u>Tamarix</u> (saltcedar + athel) used as ornamental and shade trees in 7 of the 12 Major Land Resource Areas of Texas	307

<u>Table no.</u>	<u>Table title</u>	<u>Page no.</u>
62	Calculation of the proportion and value of athel and saltcedar in Texas	308
63	Number and value of all trees per house in each MLRA	309
64	Twelve most used trees in Arizona and adjacent areas of neighboring states	310
65	Value of shade trees (and their beneficial close relatives) in Arizona and neighboring states that are also weedy trees of rangelands	311
66	Insects and mites that attack <u>Tamarix</u> spp. in Israel, Turkey, Iran, and western India	323
67	Suitability of insects and mites from Israel, Turkey, Iran and western India as biocontrol agents for saltcedar in North America	325
68	The galls of <u>Tamarix</u> (not found on <u>I. aphylla</u> ), their causative agents, distribution in Israel and the Sinai and their characteristics	328
69	Insect herbivores that attack various species of <u>Tamarix</u> in Pakistan	330
70	Costs of combination mechanical and chemical control of saltcedar	357
71	Economic account for 50 and 90% saltcedar control programs	368
72	Environmental account for 50 and 90% saltcedar control programs	371
73	Social well-being account for 50 and 90% saltcedar control programs	375
74	Summary of environmental account of the projected effects of 50% or 90% effective biocontrol programs for saltcedar	380
75	Summary of social well-being account of the projected effects of 50% or 90% effective biocontrol programs for saltcedar	381

## LIST OF FIGURES

<u>Figure no.</u>	<u>Figure title</u>	<u>Page no.</u>
1	Diagrammatic representation of the principal migration routes of <u>Tamarix</u>	12
2	Summary of the distribution of the species of <u>Tamarix</u>	13
3	Saltcedar ( <u>Tamarix chinensis</u> or <u>T. ramosissima</u> ) on the Pecos River, Texas	15
4	Native distribution of <u>T. ramosissima</u> and <u>T. aphylla</u>	16
5	Native distribution of <u>Tamarix chinensis</u> , <u>T. parviflora</u> and <u>T. gallica</u>	17
6	Climatograms from saltcedar-infested areas of the U.S. compared with those in Asia where natural enemies are known	20
7	Climatograms of Pakistan in areas where <u>Tamarix</u> occurs	21
8	Distribution of saltcedar in the United States	23
9	Changes in type and distribution of vegetation in the Gila River Valley, AZ	44
10	Foliage volume characteristics of structural types	105
11	Map showing the approximate breeding ranges of the 12 subspecies of white-winged dove	143
12	The principal nesting and wintering areas of migratory white-winged dove populations in North America	144
13	Income levels of United States hunters who hunted whitewings in Texas and Mexico in 1975	182
14	Relative densities of breeding mourning doves by physiographic region, 1965-73	185
15	Average monthly densities (N/40 ha) of Gambel's quail in all riparian vegetation in the Lower Colorado River Valley	192
16	Average seasonal densities (N/40 ha) in six plant communities and habitat breadth for Gambel's quail for 1975-1978	193

<u>Figure no.</u>	<u>Figure title</u>	<u>Page no.</u>
17	Relation between depth to water and water used by plants in tanks, October 1, 1943, to September 22, 1944	218
18	Relation between maximum temperature and transpiration by saltcedar, October 1, 1943, to September 22, 1944	219
19	Total water use per year in six evapotranspirometers versus specific conductance of the saturation extract of soil samples taken from the root zones in July or August of each year	224
20	Accumulated water use in six evapotranspirometers during 1966 showing the effects of density of stand and salinity of artificially maintained ground water	225
21	Effects of changing the depth of the water table on use of water by saltcedar in two lysimeter tanks at Bernardo, NM	232
22	Relationship between water use by saltcedar and age of plants in lysimeter tanks at Bernardo, NM, 1962-1968	233
23	Computed evapotranspiration, using equation 26, versus that measured in Tank 2 at the Buckeye project in millimeters per hour for 5 periods of 3 days each	252
24	The trend of canopy diffusion resistance with respect to vapor pressure and latent energy	254
25	Solar radiation ( $K_d$ ) and leaf resistance of saltcedar, Ehrenburg, AZ, June 17, 1976	256
26	Vapor pressure deficit, leaf resistance and transpiration rate	256
27	Energy transfer over saltcedar at two sites near Bernardo, NM, June 14-15, 1977	258
28	Relationship between net photosynthesis and photon flux density for laboratory-grown and field-grown <u>Tamarix chinensis</u> plants	262
29	Net photosynthesis of laboratory-grown and field-grown <u>Tamarix chinensis</u> plants, and leaf resistance of the field-grown plant, as a function of leaf temperature	262

<u>Figure no.</u>	<u>Figure title</u>	<u>Page no.</u>
30	Diurnal patterns of air temperature, leaf resistance, net photosynthesis, and transpiration for a <u>Tamarix chinensis</u> plant on a lysimeter at Bernardo, NM, June 10-11, 1976	263
31	Measured evapotranspiration for each budget period during 1963-71 and monthly pan evaporation at San Carlos Reservoir	267
32	Average monthly ET before and after clearing based on selected ET data from all reaches	267
33	Summary of estimates of daily evapotranspiration in treated areas and replacement vegetation by the energy-budget-residual method and the eddy correlation method	271
34	Annual water use by saltcedar obtained by various workers	277
35	Relationship of water use by saltcedar to depth of groundwater from 4 large field experiments	278
36	Hypothetical use of water by saltcedar growing at different percentages of 100% volume-density	281

## PREFACE

This review of the literature on the harmful, beneficial and ecological aspects of saltcedar and its potential for successful biological control was prepared to determine whether or not a biological control program would be in the best national interest and if such a program should be initiated by the U.S. Department of Agriculture's Agriculture Research Service, in cooperation with various other interested agencies. An early draft of this report was submitted to the Technical Advisory Group for the Introduction of Biological Control Agents of Weeds (TAGIBCAW), USDA Animal and Plant Health Inspection Service (APHIS), in June 1989 and to the USDI Bureau of Reclamation, Yuma Projects Office. This review was funded as part of the ongoing research on biological control of rangeland weeds by the Grassland, Soil and Water Research Laboratory, USDA-ARS, Temple, Texas, and in part by an Interagency Agreement with the USDI's Bureau of Reclamation. This final draft incorporates changes requested by reviewers and the results of economic analysis of the harmful and benefical aspects of saltcedar, performed by Great Western Research, Mesa, AZ, under contract with the Bureau of Reclamation. It also includes information from recent reviews by Bureau of Reclamation personnel on revegetation and herbicidal controls.

## I. EXECUTIVE SUMMARY

The genus Tamarix (family Tamaricaceae) is comprised of shrubs or trees native to arid, saline regions of Eurasia and Africa. Centers of speciation are in the Iran-Pakistan-southern USSR area and the eastern Mediterranean area. Ten species have been introduced into North America since the 1830's as ornamental plants and for windbreaks. Two species of saltcedar, Tamarix chinensis and T. ramosissima, have escaped cultivation and rapidly invaded riparian areas of the western United States, especially during the 1930's, where they outcompeted and displaced most of the native vegetation. Today, they occupy over 1 million acres of prime bottomland, much of it in dense stands with little other vegetation present.

Five of the other eight species have also become naturalized but are not yet serious weeds and two species are only known as cultivated ornamentals. One species, T. aphylla, is evergreen and grows to a large tree; it is mostly beneficial as an ornamental shade tree and for windbreaks. The major conflicts of interest affecting biological control of saltcedar are its harmful values for degradation of native plant communities, for degradation of habitat for most forms of wildlife, for excessive usage of groundwater, for interference with recreational use of riparian areas, for reduced forage production for livestock, for increased sedimentation of stream floodplains, *for* blockage of stream channels and ~~flood~~ing, and for increased salination of soils. Its beneficial uses are as nesting habitat for the white-winged dove, as a pollen and nectar source for honeybees, as ornamental and shade trees, and for reducing sedimentation in reservoirs.

The biology and ecology of saltcedar gives it a strong competitive advantage over native vegetation in riparian areas, and this advantage is

What are the effects of saltcedar? further increased by several human actions:-- Fire readily kills cottonwoods and other native plants but saltcedar rapidly regrows from underground buds; the seasonal shift in floods from spring to summer caused by dams eliminates establishment of spring-blooming cottonwood and other trees but not the summer-blooming saltcedar; saltcedar is more tolerant of inundation than most native plants; the reduction in flood height below dams reduces the flushing of salt from the soil, giving the salt tolerant saltcedar an advantage; salt excreted by the saltcedar leaves forms a layer on the soil that prevents germination of other plants; and saltcedar is less browsed by livestock and wildlife and less fed on by insects than most native plants.

1) The degradation of both plant and animal communities by saltcedar invasion is well documented. Species richness is lower in saltcedar than in any other riparian communities except arrowweed and cleared areas. Saltcedar produces little food for birds or mammals: it produces no fruit, its seed are not eaten by wildlife, few animals feed on the foliage, few insects feed on it (except for an introduced cicadellid leafhopper), but many pollen- and nectar-feeding insects are attracted to the flowers. Saltcedar-infested riparian areas, therefore, have much lower value as wildlife habitat than do the areas of native-vegetation they have displaced.

Expenditure on non-consumptive usage (observing, photographing, and feeding) wildlife is worth 60% more than all kinds of hunting combined. The amount that can be roughly allocated to riparian areas in Arizona and New Mexico is \$135.6 million. The amount of losses to non-consumptive usage that can be attributed to saltcedar in these two states (not including Texas and other infested states) is from a few million to \$45 million annually under various assumptions.

2) Saltcedar damages parks and wilderness areas by violating the principal objective to maintain these areas as examples of the native flora and fauna and also by interfering with the recreational use of the parks by visitors. Many western parks have extensive infestation of saltcedar along streams, springs and lakes. Drinking water for wildlife is reduced or eliminated, and wildlife habitat is degraded. For human visitors, access to recreational areas is restricted; insects, hayfever, dust, fire and boating hazards are increased; and the aesthetic values are reduced. A 90% control of saltcedar could increase park usage by 20%, providing benefits of \$2.3 to 7.0 million annually.

3) Dense stands of saltcedar growing in river floodplains or beside lakes probably use 3 to 6 ft of water annually, depending on depth to the water table and the elevation<sup>7</sup> and climate of the area. Other riparian plants, such as cottonwood and willow, probably use similar amounts but mesquite uses less (maybe one-half as much) and four-winged saltbush, quailbush, inkweed, and some other plants use even less. The best measurement of water salvaged by clearing dense stands of saltcedar along a western river was ca. 19 in. per year, before replacement vegetation was re-established. However, the replacement vegetation would use nearly all of the water "salvaged." Although it appears that little water can be salvaged for "off site" usage for agricultural irrigation, municipal usage, etc., the water could be used "on-site" by more desirable vegetation.

4) Saltcedar probably causes substantial economic and ecological damage by sedimentation and blockage of stream channels, increasing flooding, and increasing salinity of the soil surface caused by salt excreted by the leaves.

5) Saltcedar is important as nesting habitat (but not as a food source) for the migratory white-winged dove, but only in Arizona, a small area of southwestern California, and a small area of western Texas (the dove overwinters in southern Mexico). At present, whitewings are strongly dependent on saltcedar thickets in Arizona since the original mesquite thickets mostly have been cleared or have died. Whitewings strongly prefer large saltcedar trees (15-30 ft tall) over small trees for nesting. However, present populations in the dense nesting colonies are more limited by food availability (the shift in agriculture from grain to cotton) than by nesting habitat. In New Mexico, the white-winged dove occurs only in the small southwestern corner. Saltcedar does not occur in northeastern Mexico or southern Texas where the dove is most abundant, but saltcedar does provide nesting habitat in the Trans-Pecos area where relatively small whitewing populations occur. The effects of biological control on white-winged dove hunting would depend largely on the extent to which native velvet mesquite, screwbean mesquite, and cottonwood-willow would replace saltcedar. This, in turn, depends in some areas on whether or not the decline of water tables can be halted or reversed. Revegetation programs could be implemented in some areas if native vegetation did not return naturally after saltcedar stands are thinned following biological control.

The great nesting colonies of the white-winged dove, which attract large numbers of dove hunters, occur only in dense riparian vegetation from 20 to 30 ft tall. According to the accounts of the earliest travelers in the Southwest, whitewings were common but not unusually abundant. The huge nesting colonies apparently were produced later by the opportune balance of nesting habitat and cultivated grain fields. In Arizona, the white-winged dove still thrives in disperse populations over thousands of square miles of

desert where most of its population occurs, but these populations are too disperse to attract hunters.

Economic losses in dove hunting caused by a 50% effective program for biological control of saltcedar were estimated at \$500,000 in Arizona and \$200,000 in Texas annually; a 90% effective program would entail losses 50% greater in Texas and twice as great in Arizona. These losses assume no replacement of saltcedar. If the native vegetation, especially mesquite, returned as the saltcedar declined, or if successful revegetation projects were carried out, these losses would be reduced or would disappear.

6) Tamarix is widely, but not abundantly, used in the southwestern U.S. and northern Mexico as an ornamental or shade tree around houses, in parks, etc. In the U.S., and probably also in Mexico, this usage is about half saltcedar and half athel. The total value of saltcedar used as ornamentals and for shade in the southwestern U.S. is ca. \$34 million, or 0.24% of all shade trees. The larger, evergreen athel trees would be unharmed in a biological control program. If this present value is prorated over the 10 years needed to grow replacement trees, the annual damages would be ca. \$698,000 for a 50% effective biological control program, \$1,256,000 for a 90% effective program, and none thereafter.

7) Saltcedar is of value to some beekeepers, and a few list it as the most important plant for both honey for sale and colony maintenance, although the honey produced is of rather low quality. However, the total amount of nectar and pollen available in saltcedar stands is far from being completely used by the present numbers of bees. A control of 75 to 80% of the saltcedar probably would still leave sufficient amounts for the honeybee industry. Arizona and New Mexico together have only 82,000 colonies of honeybees (1.95% of the U.S. total) that produce 4.094 million pounds of honey annually (2.20%

7  
of the U.S. total) worth ca. \$1.6 million. Based on somewhat inexact extrapolations, (we) calculated that only 6% of this production comes from saltcedar (worth \$237,000 annually). The damage to the honeybee industry likely to occur from a control of only 75-80% of saltcedar would be considerably less. Athel is not a target of biological control and would still be available in present amounts for honeybees. If the native seepwillow baccharis (which has been displaced in many areas of saltcedar) were to increase in density after saltcedar control, it would substitute for much of the honeybee needs of late summer and fall and also it would produce a better quality honey.

8) Other beneficial uses of saltcedar (fenceposts, firewood, grazing by livestock, etc.) are of very minor value. The windbreaks used in the Southwest are mostly of athel and would be unaffected by biocontrol of saltcedar.

9) The damage caused by saltcedar is far greater but is much more difficult to quantify than its beneficial values. The ecological damage caused by displacement of native plant communities and the consequent degradation of wildlife habitat cannot be converted into a like common denominator for comparison with its other effects. However, the calculated reduction in value of riparian areas for non-consumptive usage (based on expenditures for this) may be used as an indicator of the economic value man places on the ecological health of these areas, although it does not measure the intrinsic values of the ecosystem. This loss to non-consumptive usage in Arizona and New Mexico far outweighs the value of white-winged dove hunting. The loss caused to other types of hunting by saltcedar invasions (mourning dove, Gambel's quail, small and big game, and trapping of furbearers) also probably outweighs the value of whitewing hunting. The amount of mourning dove and quail hunting in Arizona is ca. 10 times that of whitewing hunting. The effects of saltcedar on these other types of hunting in New Mexico and Texas

(except Trans-Pecos Texas) are entirely negative since they are not partially offset there by benefits of saltcedar to whitewings. Also, losses caused by saltcedar through excessive usage of groundwater, increased sedimentation, flooding and increased soil salinity are probably very great but have not been documented in the literature in economic terms. *Journal?*

10) An economic analysis indicated that in the Economic Account annual benefits over losses resulting from a 50% effective biological control program would total \$22 million and those from a 90% effective control program would total \$40 to 60 million. Positive economic benefits would occur in water use, livestock forage, flooding, and recreation. Losses would accrue to dove hunting, honeybees, ornamentals, and sedimentation. In the Environmental Account, biological control provided a small beneficial increase over baseline for 10 agricultural-recreational factors, a moderate increase for 36 wildlife species, and a large increase for 42 plant species considered. No factors were strongly adversely affected but several were strongly benefited. In the Social Account, biological control provided moderate beneficial increases for the 5 categories considered; none were strongly adversely affected but a few were strongly benefited.

11) Currently used herbicidal and mechanical controls are expensive, often require more than one application to obtain control, and require frequent maintenance applications. The plant is difficult to kill because of resprouting from crown buds and roots and the multiple use requirements of the riparian habitat make undesirable those controls that kill a broad range of plant species.

12) Biological control has excellent potential for providing good control of saltcedar by the introduction of natural enemies (mainly insects) from its area of natural distribution in Asia and possibly southern Europe. Numerous

insect species are known to attack saltcedar in Israel, Turkey, Italy, Pakistan, and southern USSR, and additional explorations should reveal more species and also plant pathogens. Preliminary testing in Israel and Pakistan has revealed several promising insect and mite species for introduction. No native plant or crop species in North America are closely related (in the same plant family) to saltcedar. The risk to non-target native plants, therefore, would be exceptionally low in relation with past biological control projects for other weeds. A goal of 75-80% decrease in density of stands would appear to be obtainable but stands would not be eliminated. A gradual decline in stands, with a concurrent increase in the regrowth of native vegetation and consequent improvement in wildlife habitat would be anticipated. Sufficient saltcedar would remain for a substantial part of the needs of beekeepers. Insects would be introduced that attacked saltcedar but not athel, thus preserving athel for honeybees and for shade trees. Insects that attack young saltcedar plants but not large trees would be most desirable because young trees have no value for white-winged doves or other wildlife and also use more water than older plants; however, such insects have not been identified to date. Biological control would provide permanent control and would not harm other beneficial vegetation, would not pollute the soil or water, and would be the least costly of all control measures since only the one-time cost of the research is required.

13) Experience with numerous revegetation projects on western rivers has elucidated many, if not all, of the criteria for successful establishment and growth. Several tree and shrub species have been used, and improved selections are available, that are adapted to various conditions of soil and groundwater salinity and depth to the water table. Methods of planting, irrigation, water conservation, protection from browsing, insect damage, and

weed protection have been developed that go far toward insuring a high success rate, particularly if proper sites for revegetation are selected. Costs are still high but can be greatly reduced by proper site selection and using the best methodologies. Successful revegetation can replace saltcedar with more desirable trees and shrubs, reduce flooding, in some cases reduce consumptive use of water, and also greatly improve wildlife habitat and livestock production. Revegetation should be considered a viable option if the native vegetation does not return naturally and quickly enough after saltcedar control.

13) A project on biological control of saltcedar by the introduction of natural enemies from the area of its native distribution in Asia and the Mediterranean area would be highly beneficial to the overall well-being of the United States and probably also of Mexico. The damage done by saltcedar far outweighs its beneficial values, the potential for successful biological control is excellent, and the risk to non-target plant species is exceptionally low.

## II. INTRODUCTION

The following study was begun in January 1987 with the approval of an Inter-Agency Agreement between the USDI-Bureau of Reclamation, Lower Colorado Region and the USDA-Agricultural Research Service, Temple, Texas, funded in part by the Bureau of Reclamation.

The purpose of the study was to review the information currently available on the harmful, beneficial and ecological aspects of saltcedar and to determine whether or not biological control of the <sup>invading, foreign</sup> plant was feasible and should be pursued. The end result of this stage was to submit a report to Reclamation and to the Technical Advisory Group on the Introduction of Biological Control Agents of Weeds, USDA-APHIS, seeking their opinion on a resolution of the conflicts of interest and requesting authorization to proceed with a biological control program. If approved, the approach would be to introduce insects or other natural enemies of saltcedar from its area of natural distribution in Asia and southern Europe.

In addition, new research information was to be gathered in areas where previous work was inadequate, all funded by the Bureau of Reclamation. These subprojects were:

- 1) Determine the distribution and abundance of saltcedar in Mexico. This project was begun with the Dept. of Recursos Naturales, Universidad Autonoma Agraria "Antonio Narro," Saltillo, Coahuila, Mexico. Unfortunately, <sup>purely</sup> funding was not received until January 1989. <sup>at last</sup> The first check was lost by the American Embassy at Mexico City in November 1987; subsequent procedures for certification of the loss and reissue of another check, and substantiated delays at every stage of the process, delayed reissue for over a year, and the research could not start until that time. <sup>began some of the</sup>
- 2) Determine the usage and value of saltcedar as a shade or ornamental yard tree in the southwest. This research was in cooperation with the USDA-ARS Aridland

Watershed Management Research Group, Tucson, AZ. The research was completed during the summer of 1987.

- 3) Determine the extent and the importance of saltcedar as habitat for the white-winged dove in Mexico. This research was done in cooperation with the Chihuahuan Desert Research Institute, Alpine, TX. The first survey trip was made to northwestern Mexico in May 1987 and a second trip was made in May and June 1988 to Sonora and Sinaloa.
- 4) Develop methods of remote sensing so that saltcedar could be identified and its area of infestation measured by aerial photography. This research was in cooperation with the USDA-ARS Remote Sensing Research Unit, Weslaco, TX.

Final reports on these subprojects are included as appendices of this report, except for subproject (1) which is still in progress.

### III. TAXONOMY AND WORLDWIDE DISTRIBUTION OF SALT CEDAR

Saltcedar is in the genus Tamarix, family Tamaricaceae. Most recent classifications place the family Tamaricaceae in the small order Tamaricales, along with <sup>distinct</sup> Frankeniaceae (Thorne 1976) ~~and/or Fouquieriaceae~~ (Takhtajan 1980), or <sup>as a 2 family group</sup> in the larger order Violales (Thorne 1983, Cronquist 1988). These hypotheses, based largely on reproductive features, are also supported by the anatomically similar salt glands and by the production of D-pinitol by members of both Frankeniaceae and Tamaricaceae (Crins 1989).

Tamaricaceae is a relatively small family of six genera (Tamarix, Hololachna, Myricaria, Myrtama, Reaumuria, and Tamaricaria) and about 100 species, occurring primarily in central Asia, the Middle East, northern Africa and the Mediterranean area of Europe (Crins 1989, Qaiser 1976).

*According to some taxonomists (Thorne 1992) only Tamarix, Myricaria, and Reaumuria*  
Qaiser (1976) recognized 4 species of Myricaria and 4 of Reaumuria in Pakistan and later Qaiser and Ali (1978) described the monotypic genus Tamaricaria from there. None of these <sup>six</sup> genera have species native in the Western Hemisphere.

Baum (1978) recognized 54 species in the genus Tamarix. The native distribution <sup>of</sup> the various species ranged from <sup>south</sup> eastern Asia to southern Europe and North Africa, with a few species in western and southern Africa.

The probable site of origin of the genus is the steppes and deserts of Iran, Afghanistan, Pakistan, and south-central USSR, with a secondary center of speciation in the eastern Mediterranean area, (Fig. 1). Baum (1978) listed the species occurring in each country (Fig. 2). Qaiser (1981) recognized 26 species from Pakistan, including I. aphylla, I. ramosissima and 5 new species; he disagreed with the designations of some species made by Baum (1978).

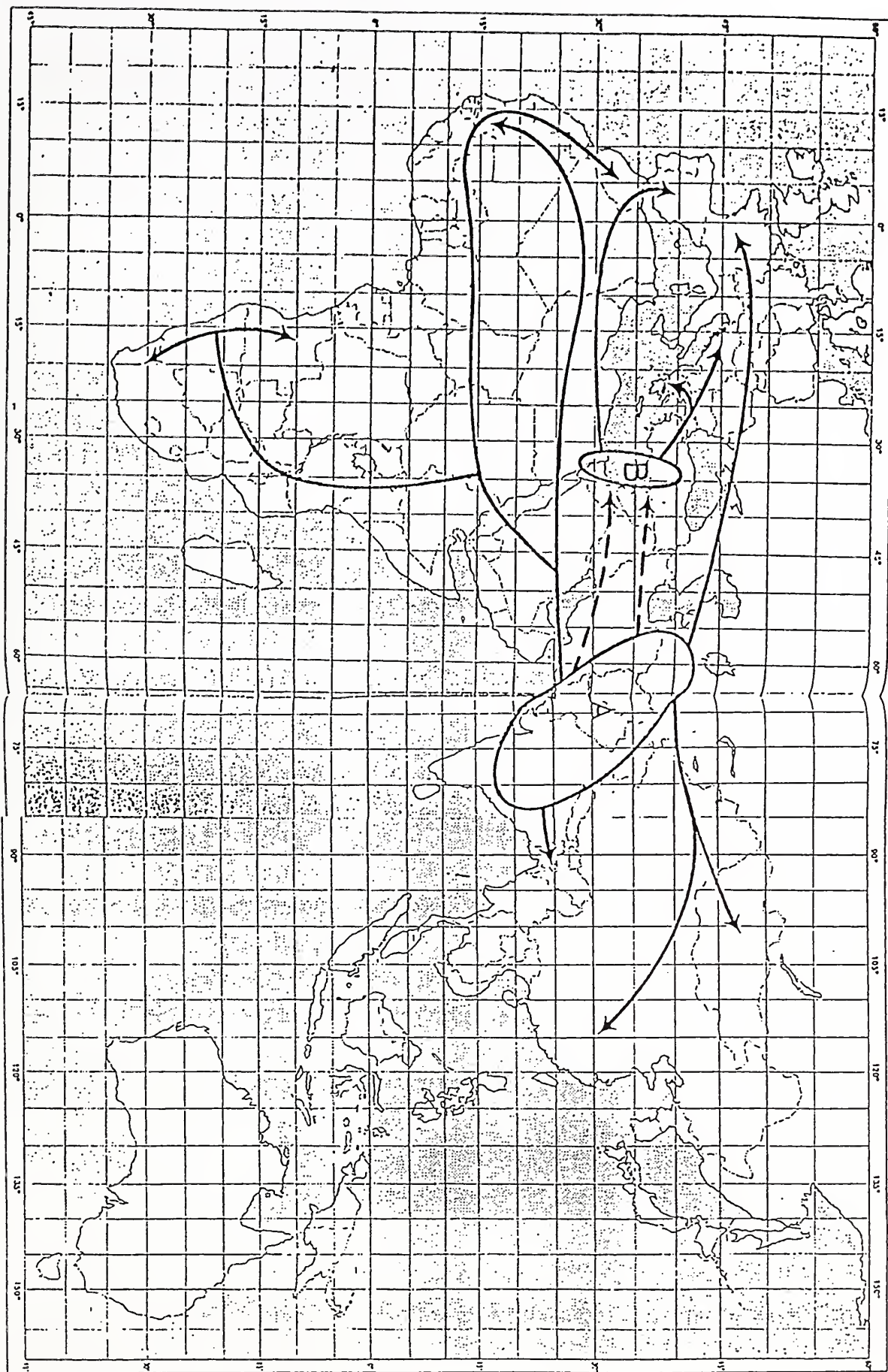


Fig. Diagrammatic representation of the principal migration routes of Iamarix. A denotes the center of the East-Mediterranean center (from Baum 1978).

SECTION	SERIES	SPECIES	COUNTRY OR AREA	CHOROTYPE
Tamarix	Gallieae	<i>T. arbuscula</i>	SWITZERLAND	IT
		<i>T. gallica</i>	Spain	NW-N-Eur S-S
		<i>T. korolkowii</i>	Spain	IT
		<i>T. marschallensis</i>	Spain	E-Sud
		<i>T. palustris</i>	Spain	Endemic
		<i>T. rostrata</i>	Spain	IT-Eur Sub
		<i>T. smyrnensis</i>	Spain	E-M-IT
		<i>T. arbuscula</i>	Spain	IT
		<i>T. canariensis</i>	Spain	Sud ISAI
		<i>T. hisida</i>	Spain	WM
Leptodactylae	Leptodactylae	<i>T. indica</i>	India	IT
		<i>T. karakulensis</i>	India	IT
		<i>T. leucostachya</i>	India	IT-Eur Sub
		<i>T. mannifera</i>	India	SA-E-Sud
		<i>T. rubra</i>	India	E-Sud (E Air)
		<i>T. arbuscula</i>	India	E-Sud
		<i>T. sonchifolia</i>	India	W-Sud
		<i>T. annulata</i>	India	SW Air
		<i>T. opulenta</i>	India	Sud ISAI
		<i>T. berberidensis</i>	India	Endemic
Vaginatae	Vaginatae	<i>T. dioica</i>	India	Indian
		<i>T. ussuriensis</i>	India	SW Air
		<i>T. chinensis</i>	India	Sud-Japanese
		<i>T. gracilis</i>	India	IT (Eur. SW)
		<i>T. lasiocarpa</i>	India	IT
		<i>T. sinensis</i>	India	WM-Asianic
		<i>T. sinensis</i>	India	SA (Sud)
		<i>T. brachystachya</i>	India	IT (Eur Sub)
		<i>T. diandra</i>	India	NM
		<i>T. elongata</i>	India	IT (Eur Sub)
Antandreae	Antandreae	<i>T. hamocarpa</i>	India	NM (E Air)
		<i>T. meyeri</i>	India	IT
		<i>T. octandria</i>	India	IT (Eur S-S)
		<i>T. rosea</i>	India	IT (Eur S-S)
		<i>T. latifolia</i>	India	SA (IT ISAI)
		<i>T. latifolia</i>	India	AI-Eur S-S
		<i>T. latifolia</i>	India	IT (Eur S-S)
		<i>T. latifolia</i>	India	IT
		<i>T. latifolia</i>	India	IT
		<i>T. latifolia</i>	India	IT
Arbusculae	Arbusculae	<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
		<i>T. arbuscula</i>	India	IT
Fasciculatae	Fasciculatae	<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
		<i>T. fasciculata</i>	India	IT
Arabiceae	Arabiceae	<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
		<i>T. arabica</i>	India	IT
Pleandreae	Pleandreae	<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT
		<i>T. pleandrea</i>	India	IT

## LEGEND

Alr.	-African
E	-East
Eur. Sib.	-Euro-Siberian
IT	-Irano-Turanian
M	-Mediterranean
NL	-North
S	-South
SA	-Saharo-Arabian
Sud	-Sudanic
( )	-penetration
W.	-West

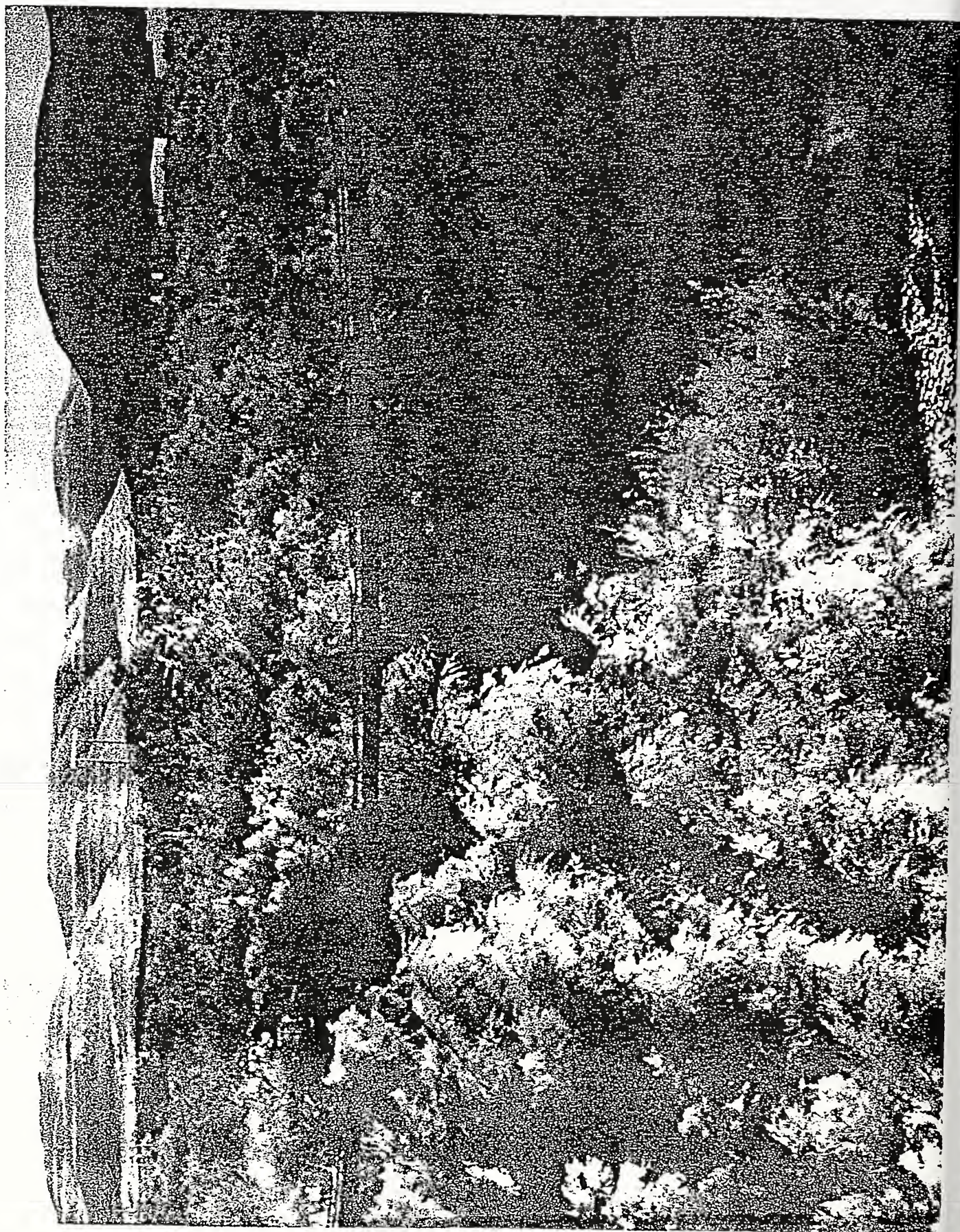
Total Species per Area

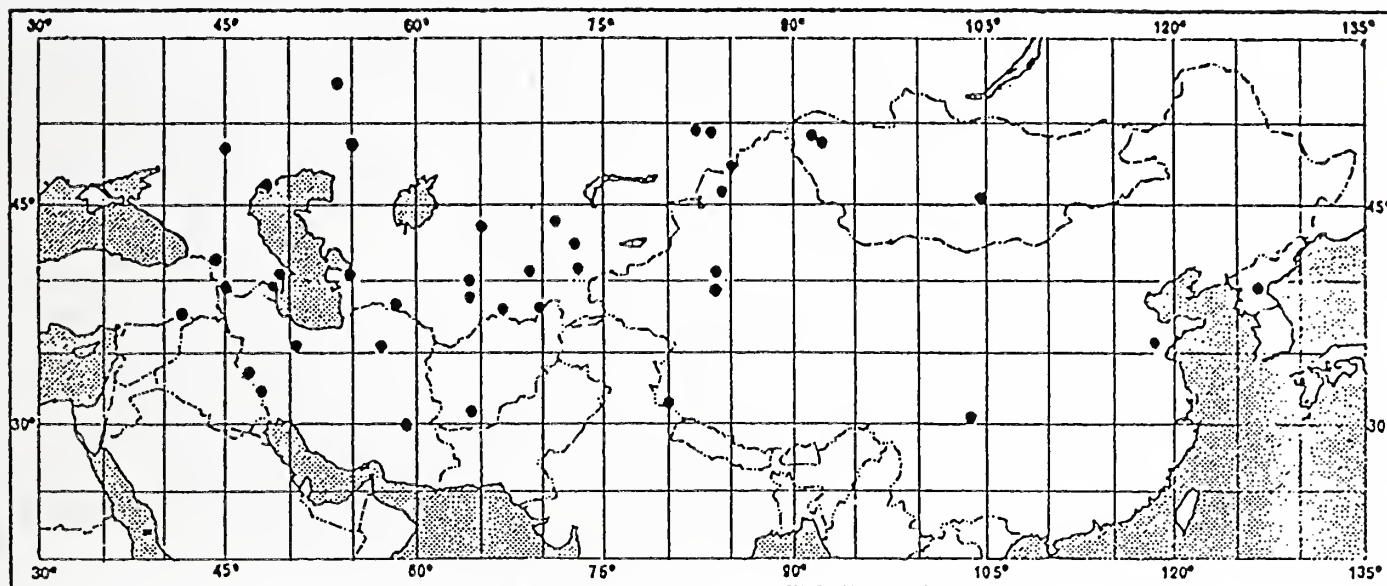
\* Species introduced into the United States.

*T. parviflora* DC. (4 stamens) is common but  
seldom if ever weedy in the Southwest, 14

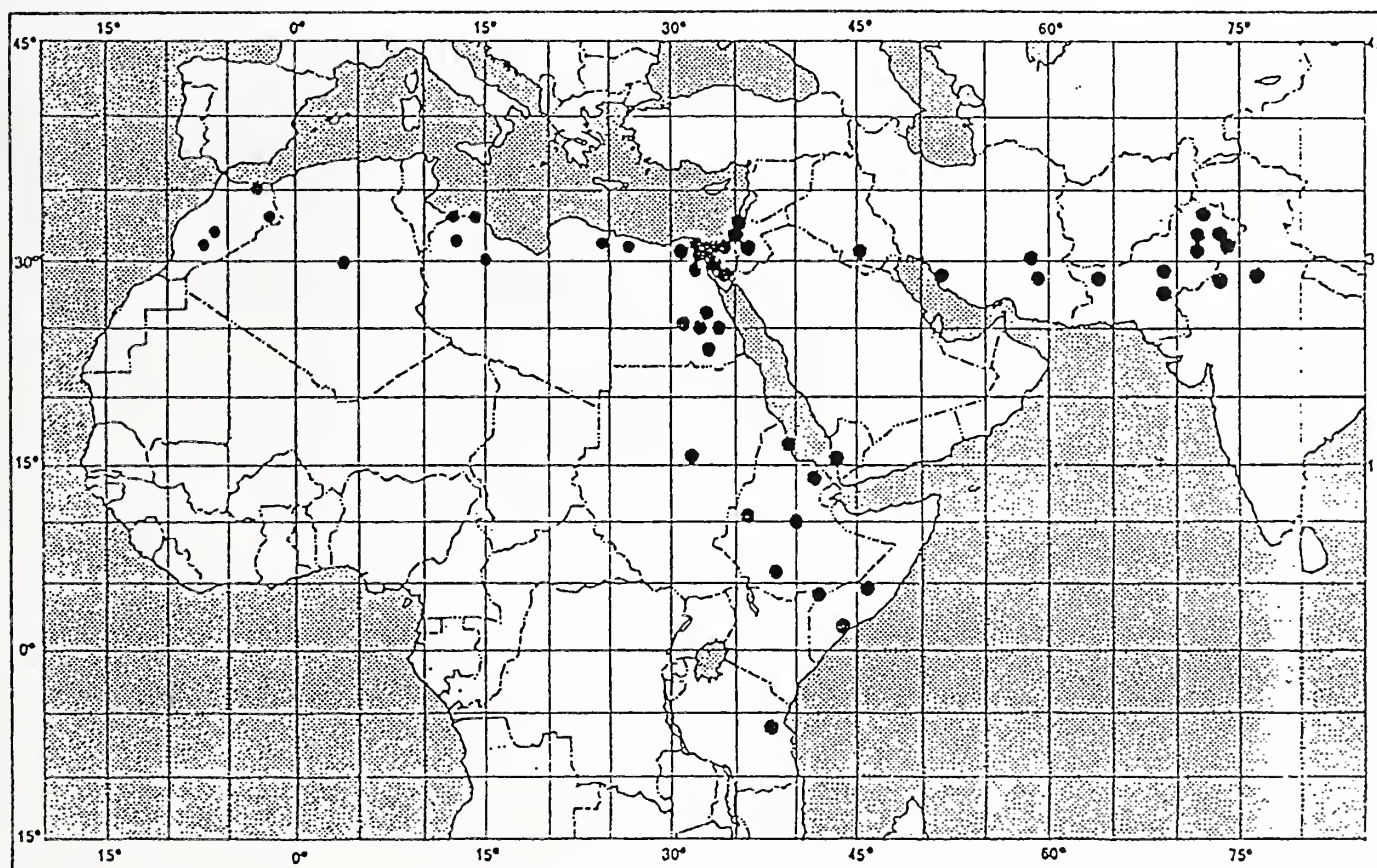
Ten species have been introduced into the U.S. and Canada. Baum (1967) reported that the most abundant were *I. ramosissima* Ledeb. (~~5 stamens~~), *I. chinensis* Lour. (~~5 stamens~~), and *I. parviflora* DC. (4 stamens), ~~all of which~~ <sup>both of these have</sup> are deciduous <sup>shrubs or small trees</sup> and are invaders of western riverine systems, and *I. aphylla* (L.) Karsten which is evergreen, <sup>not cold tolerant,</sup> grows into a large tree, is widely used as an ornamental shade tree and for windbreaks, and is only rarely weedy. Baum (1967) also recognized <sup>5 deciduous</sup> 4 other species: *I. africana* Poiret (not common), *I. aralensis* Bge. (rare), *I. canariensis* Willd. (recently introduced), and *I. gallica* L. (rare). Crins (1989) found that 6 species have become naturalized in the southeastern U.S. (*I. gallica*, *I. ramosissima*, *I. canariensis*, *I. africana*, *I. tetragyna* Ehrenb. and *I. parviflora*); also, *I. mascatensis* Bunge had been cultivated but not yet escaped. Horton (1977), after studying herbarium specimens and observing many growing plants, was unable to distinguish between *I. chinensis* and *I. ramosissima*. Subsequent authors have usually referred to this taxon as *I. chinensis* since this name has priority. Crins (1989) also stated, "It is difficult to see how these taxa can be recognized as different species, let alone members of different sections of the genus!" This ~~is the taxon~~ <sup>(*I. ramosissima*/*I. chinensis*) Fig 3</sup> ~~that~~ <sup>and</sup> has invaded western U.S. and northern Mexican riparian areas, ~~that~~ <sup>many</sup> has displaced a large proportion of the native vegetation, ~~and against which the vast majority of~~ <sup>the</sup> control programs have been directed <sup>toward controlling it.</sup>

Baum (1978) gives the native ranges of all species of *Tamarix*. The native range of *I. ramosissima* is throughout central Asia, from Turkey and Iran to China, Mongolia, and Korea (Fig. 4). The native range of *I. parviflora* is mostly northern Mediterranean from Italy, through Yugoslavia and Greece to Turkey while *I. gallica* occurs in Italy and western Europe (Fig. 5). The native range of *I. chinensis* is throughout China and to Korea



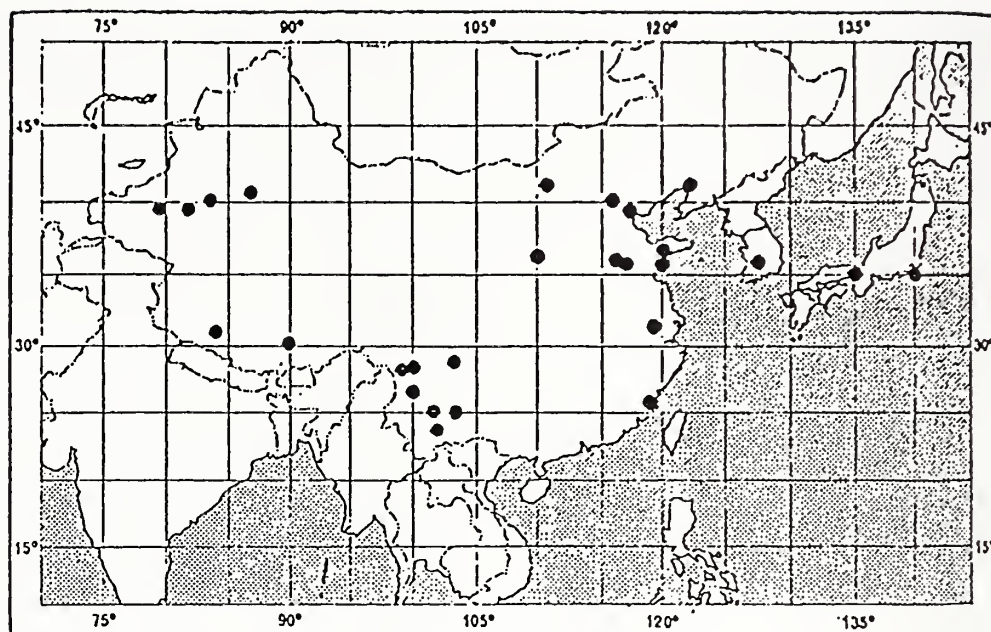


A. Tamarix ramosissima

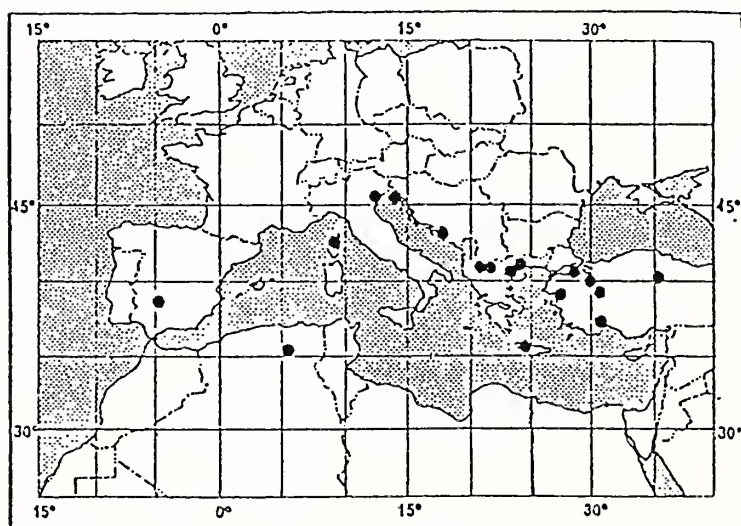


B. T. aphylla

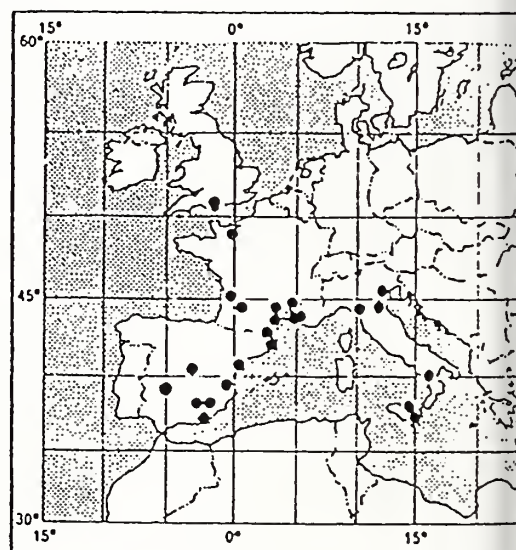
Fig. 4 Native distribution of T. ramosissima<sup>(A)</sup> and T. aphylla<sup>(B)</sup> (from Baum 1978).



A. *Tamarix chinensis*



B. *T. parviflora*



C. *T. gallica*

Fig. 5 Native distribution of *Tamarix chinensis*, *T. parviflora*, and *T. gallica* (from Baum 1978).

and Japan (Fig. 5). Tamarix aphylla has the largest natural distribution, occurring from Morocco across northern Africa to Syria and to Pakistan and down the eastern side of Africa to Tanzania (Fig. 4).

Frankeniaceae is a small family of four genera and ca. 80 species of halophytic desert herbs or subshrubs of tropical and temperate distribution (Whalen 1980, 1987). Frankenia is the largest <sup>the</sup> genus and only <sup>of the family</sup> ~~it is~~ <sup>native</sup> represented in the Western Hemisphere. Frankenia has a number of species in the Mediterranean area, a large group of species in Australia, another in Chile, and a smaller group in southwestern North America. One species, F. pulverulenta, is found more or less continuously from Europe to central Asia and through Africa to the Cape (Good 1974).

Whalen (1980, 1987) recognized 7 species of Frankenia native in desertic areas of the southwestern United States and northern Mexico. These are F. jamesii in Trans-Pecos Texas, New Mexico and Colorado; F. grandiflora in southern California; F. gypsophila in Nuevo Leon, F. johnstonii in Nuevo Leon and southern Texas; F. margaritae in Nuevo Leon; F. palmeri in Baja California and Sonora; and F. salina in Baja California. <sup>Two other species</sup> ~~are native in the Western Hemisphere, F. patagonica and F. juniperoides, both from Chubut, Argentina.~~ <sup>Two other species</sup> ~~are native in the Western Hemisphere, F. patagonica and F. juniperoides, both from Chubut, Argentina.~~ One species, F. johnstonii, is on the federal list of endangered species. None of these are of economic nor of notable ecological importance (i.e., they are not major components of plant communities and no species of vertebrates are known to depend on them for a livelihood).

Some areas of North America where Tamarix occurs are remarkably similar in climate (temperature and rainfall amounts and patterns) to areas of the Old World where Tamarix is native. For example, some areas of Utah are similar to south-central USSR, central Kansas to eastern Yugoslavia,

northwestern Mexico to north-central India, and Montana is somewhat less similar to northern China (Fig. 6). The greatest similarities exist between areas of the Southwest and areas of central Pakistan (Fig. 7). (Explanation of the climate-diagrams is given in Fig. 7a.) However, since Tamarix is a riparian species, rainfall patterns probably are of less importance in how well it grows than is temperature. Also, some of the U.S. species occurring in areas of summer rainfall apparently came from the much different Mediterranean climatic zone (winter rainfall and dry summers) of southern Europe and the Middle East. However, the survival and increase of insect herbivores and plant pathogens used as biocontrol agents may be ~~much~~ more influenced by rainfall patterns than is plant growth.

pages 20 & 21  
found in review order

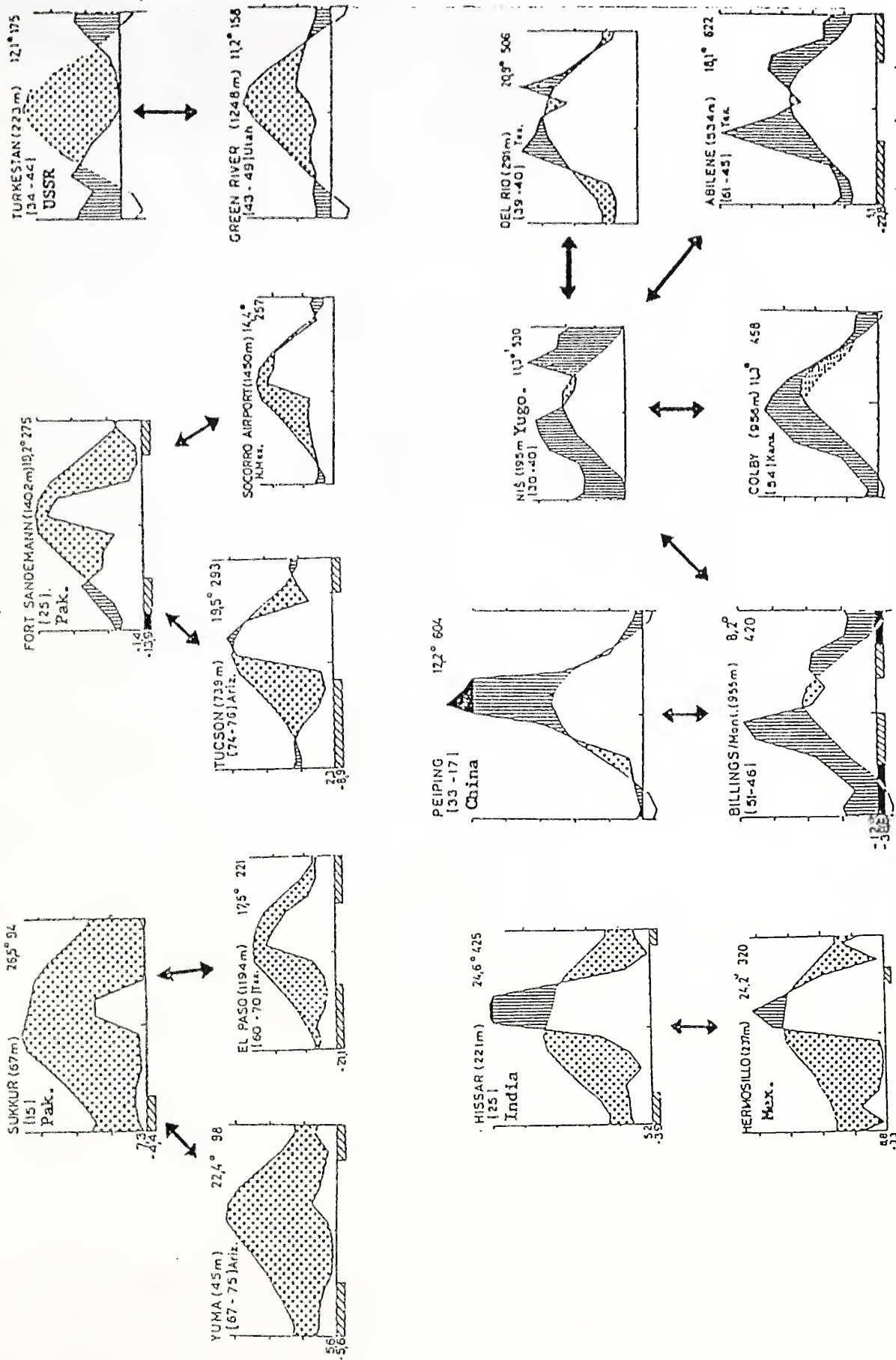


Fig. 6 Climatograms from salcedar-infested areas of the U.S. compared with those in Asia where natural enemies are known (from Walter et al. 1975).

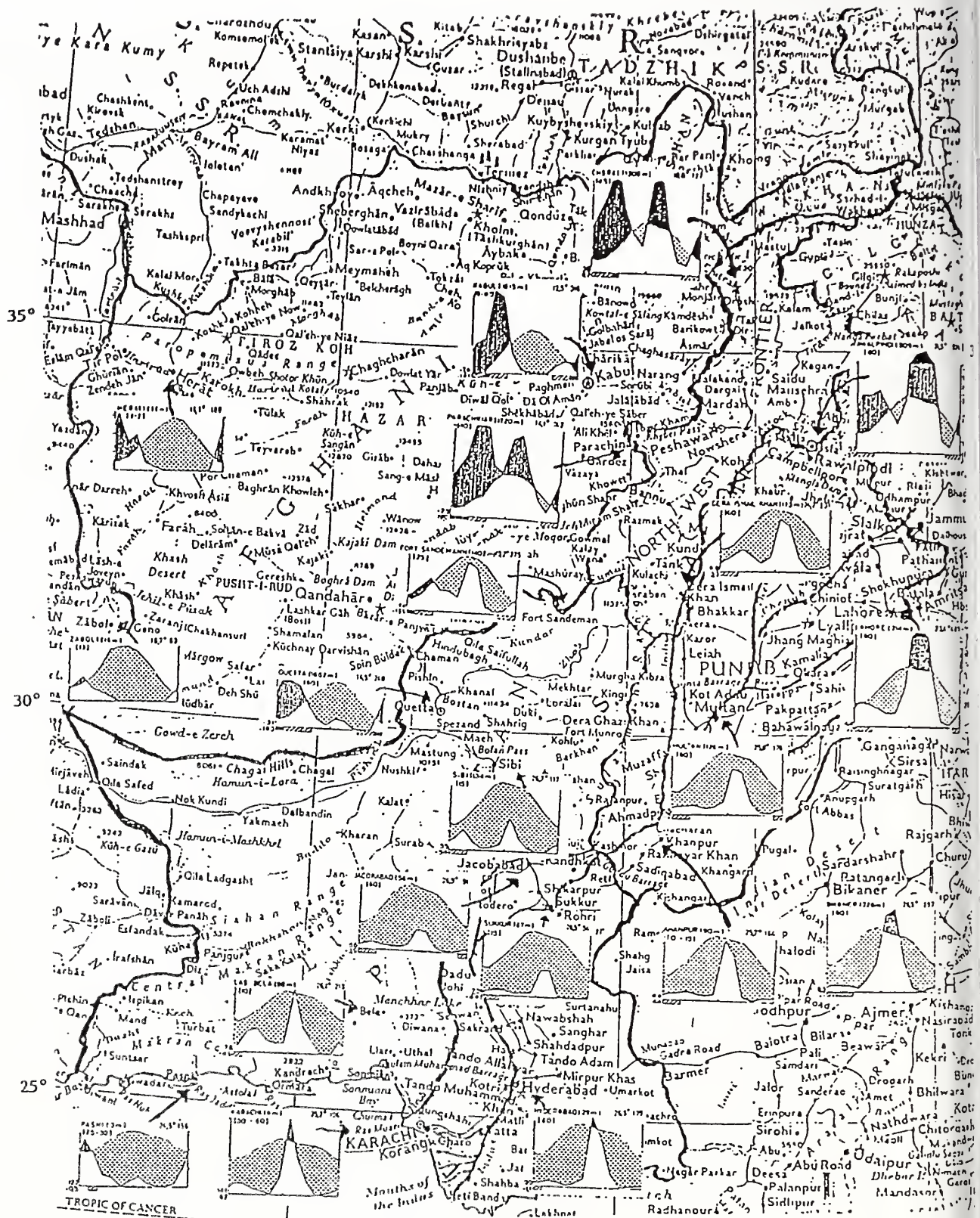


Fig. 7 Climatograms of Pakistan in areas where *Tamarix* occurs (climate diagrams from Walter et al. 1975).

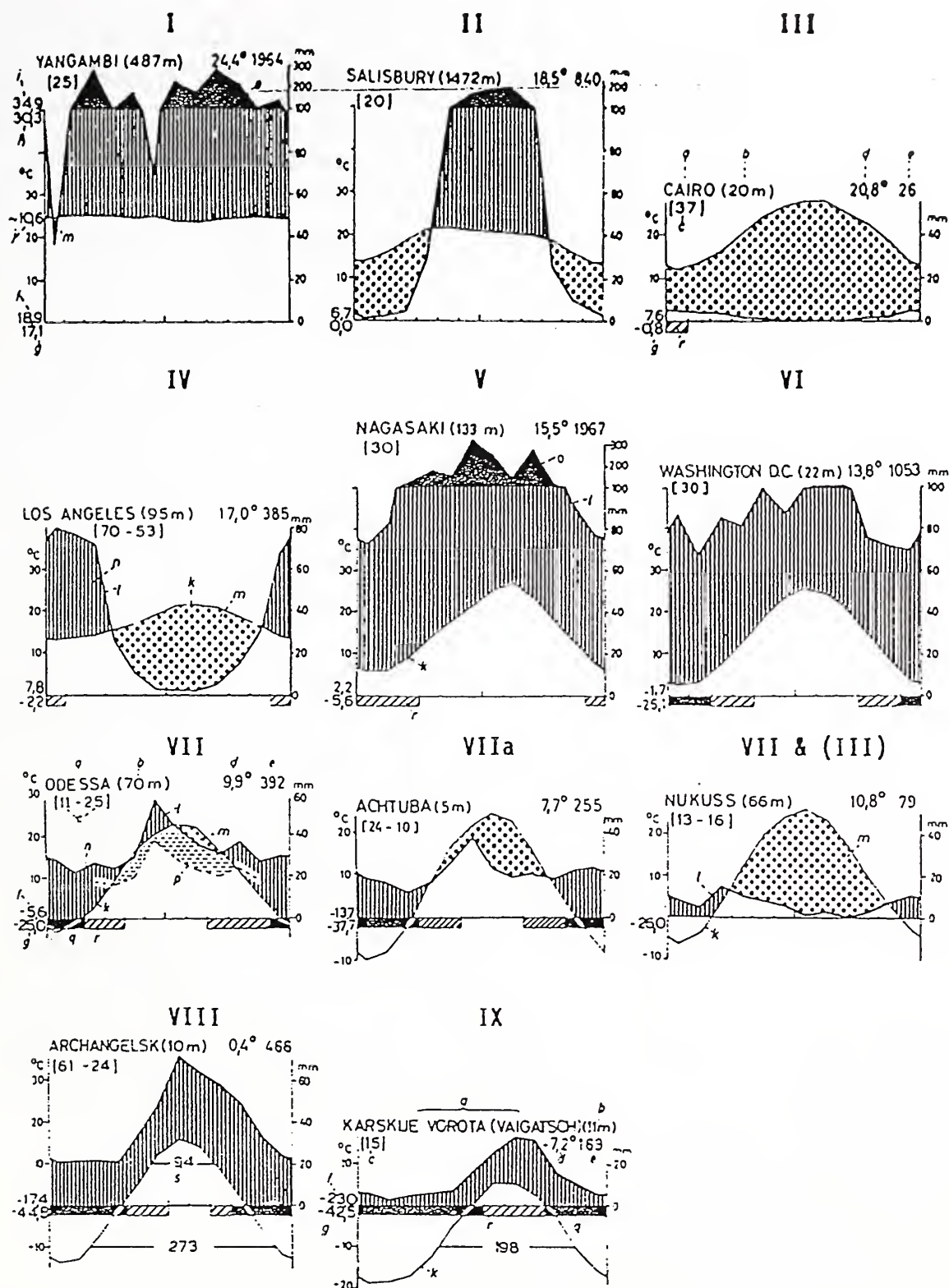


Fig. 7a Explanation of the climate-diagrams (from Walter et al. 1975).  
 Abscissa (horizontal axis): Shows the months from January to December for the diagrams on the northern hemisphere; for those on the southern hemisphere, the months shown on the abscissa are from July to June. By this arrangement, the warm season of the year is always in the center of the diagrams. Ordinate (vertical axis): the first dash-mark upwards represents  $10^{\circ}\text{C}$  and 20 mm, respectively. (The numbers are usually omitted as, for example, on Fig. 3).  
 The symbols and numbers on the diagrams have the following meaning (see particularly the diagram of Odessa):

a = station; b = height above sea level in meters; c = number of years with records (first number, where shown, refers to temperature, second number to precipitation records); d = mean annual temperature ( $^{\circ}\text{C}$ ); e = mean annual precipitation (mm); f = mean daily minimum temperature of the coldest month; g = absolute minimum temperature (the lowest measured); h = mean daily maximum temperature of the warmest month; i = absolute maximum temperature (the highest measured); j = mean daily temperature range. Note: Information items h, i and j are entered only for tropical stations with a daily season climate. k = curve of mean monthly temperatures (one scale interval =  $10^{\circ}\text{C}$ ); l = curve of mean monthly precipitation (one scale interval = 20 mm; thus, the ratio of temperature to precipitation = 1:2); m = relatively droughty season (dotted field); n = relatively humid season (vertical hatching); o = mean monthly precipitation in excess of 100 mm (black field; note, the scale is reduced to 1:10 so that one scale interval represents 200 mm; e.g., Yangambi or Salisbury. The reduction in scale was required to keep the diagrams from becoming large (see Cherrapunji on Fig. 4); p = precipitation curve lowered to the scale of  $10^{\circ}\text{C}$  = 30 mm, above this a horizontally hatched field = relatively dry season (applied only to stations in the steppe region); q = months with mean daily minimum under  $0^{\circ}\text{C}$  (black) = cold season of the year; r = months with absolute minimum temperatures under  $0^{\circ}\text{C}$  (angle hatched). This implies a probability of late or early frosts; s = number of days with mean temperature above  $+10^{\circ}\text{C}$ , e. g., Archangelsk; t = number of days with mean temperatures above  $-10^{\circ}\text{C}$  (e.g., Archangelsk and Karskije Vorota); s and t are shown only for stations in cold climates.

The entire set of values (from a to t) is not always available for a climatic station. Wherever certain values are not available, the respective places on the diagram are left vacant (e.g., f, q and r on the diagram for Nukuss).

The following diagrams are examples for the 9 main types: Yangambi at the central part of the Congo for type I, Salisbury in Rhodesia for type II (tropical summer-rain climate), Cairo at the lower Nile for type III (subtropical desert climate), Los Angeles in southern California for type IV (winter-rain climate), Nagasaki in Japan for type V (warm-temperate climate), Washington, D.C. in eastern North America for type VI (temperate climate with short, cold season), Odessa on the Black Sea for type VII (temperate semi-arid steppe-climate with a long dry season and moderate drought), Achutba on the lower Volga for type VIIa (arid climate of semi-desert in the temperate zone with summer drought season and cold winter), Nukuss in Central Asia for type VII(rIII) (extremely arid desert climate with cold winters), Archangelsk in the boreal taiga zone for type VIII (cold-temperate climate with very long winter), Karskije Vorota on the island of Waigach for type IX (arctic tundra climate with July mean temperatures under  $+10^{\circ}\text{C}$ ).

#### IV. SPREAD AND ABUNDANCE OF SALT CEDAR IN THE U.S.

A few species of Tamarix have been introduced into the U.S. as ornamentals, beginning in the early 1800's. Tamarix chinensis and T. aphylla were introduced into the United States from the Middle East for ornamentals and erosion control as early as 1856 (Robinson 1965). These began escaping cultivation in the late 1800's and subsequently invaded riparian sites along most southwestern U.S. rivers. Saltcedar began to spread rapidly from 1925 to 1960, with the most rapid spread from 1935 to 1955 (Christensen 1962, Horton 1977). Christensen (1962) concluded that tamarisk spread at the rate of 20 km per year through the Colorado River system. The rate of spread has since slowed as the areas with suitable habitat became filled. However, it appears to be still increasing its dominance in areas previously colonized. Bowser (1957) reported that in the Southwest, saltcedar did not spread rapidly above 4000 ft. elevation although it occurred at 9000-11,000 ft.

Robinson (1965) published a generalized map showing saltcedar infestations of waterways in the U.S. (Fig. 8). He estimated that 900,000 acres (364,400 ha) were infested in the U.S. ~~in~~ <sup>by</sup> 1960 and he predicted that 1,300,000 acres (526,000 ha) would be infested ~~in~~ <sup>by</sup> 1970, which would use 5 million acre feet of water per year. Some authors have speculated that this area infested and amount of water used are considerably overestimated (van Hylckama 1980a). Since that time, more exact estimates of area infested have been made in several selected study sites in several states (see Section IV-A of this report).

Remote sensing was first used to distinguish saltcedar by Ruff et al. (1973) on the Pecos River, NM. Recently, Everitt and DeLoach (1990), as a part of the present study, have developed technology by which quite precise

UNITED STATES DEPARTMENT OF THE INTERIOR  
GEOLOGICAL SURVEY

PROFESSIONAL PAPER 49-A  
PLATE 1

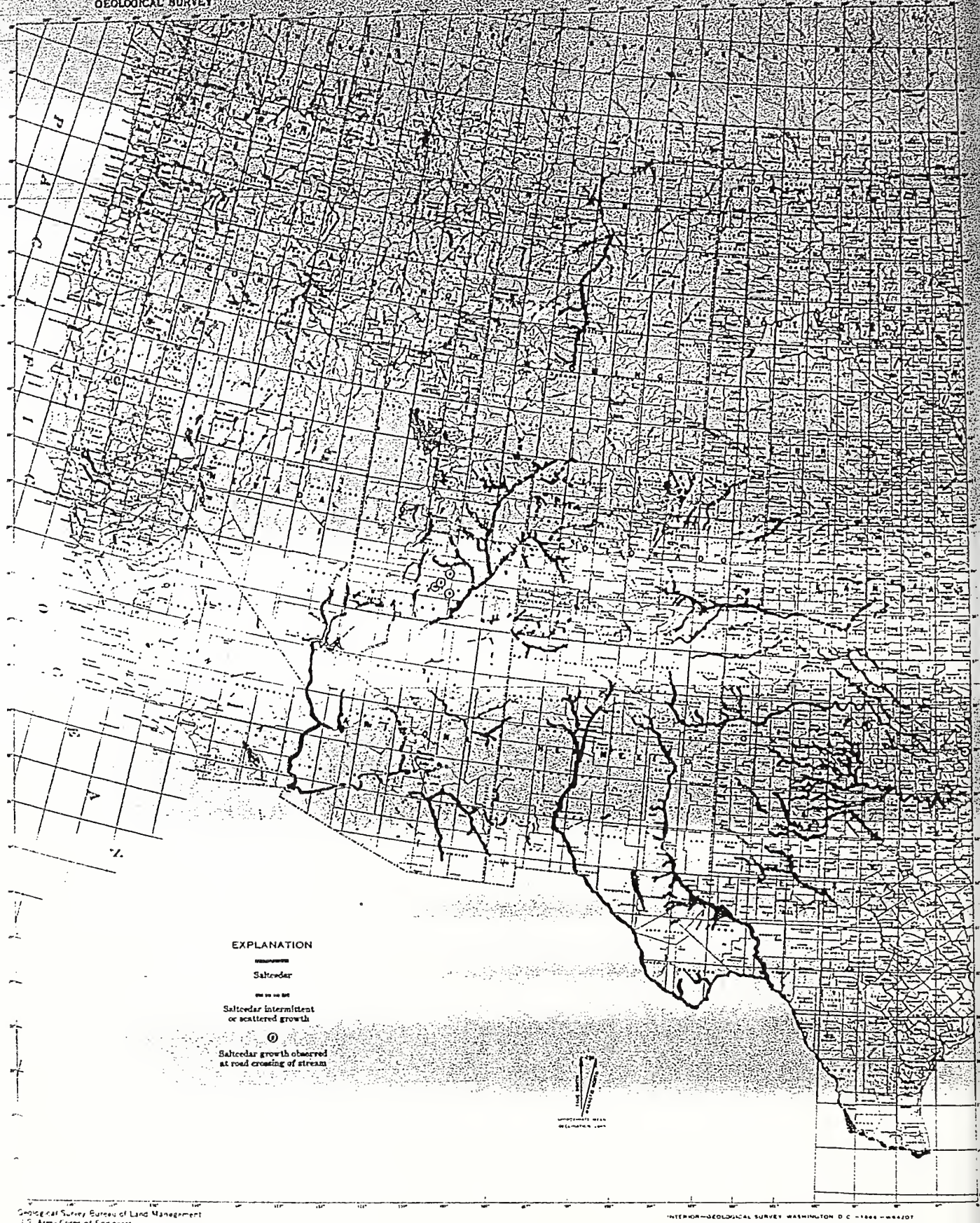


Fig. 8 Distribution of saltcedar in the United States (from Robinson 1965).

estimates of the area infested by saltcedar can be obtained by multispectral, computer analysis of normal color transparencies from low-level aerial photography (Everitt et al. in Appendix II, this report). They obtained conventional color and color-infrared aerial photographs of saltcedar during various phenological stages across the growing season and at various locations in Texas and Arizona. They made ground reflectance measurements on saltcedar and associated plant species to help interpret <sup>the</sup> aerial photographs and made ground surveys to verify <sup>the</sup> aerial photos. an analysis of the aerial photos showed that the optimum time to distinguish saltcedar in the southwestern U.S. was in ~~the~~ late fall ~~early winter~~ (November-December) when its leaves turned a yellowish-orange to orange-brown color prior to leaf drop. Saltcedar could be distinguished on both conventional color and color-infrared photographs during this phenological stage, but it had a more distinct image on conventional color photographs. <sup>The image response of</sup> Saltcedar ~~has a~~ <sup>was</sup> similar ~~image response~~ on photographs obtained in both Texas and Arizona. Optimum photographic scales for distinguishing saltcedar were 1:5000 to 1:8000. Ground reflectance measurements showed that saltcedar had higher visible (0.63-0.69  $\mu$ m) and near-infrared (0.76-0.90  $\mu$ m) reflectance than associated species, which contributed greatly to its image responses. Computer-based image analyses of conventional color film positive transparencies <sup>from</sup> showed that saltcedar populations can be quantified. With such low-altitude aerial photography, individual trees can be distinguished, the canopy area of each summed, and an accurate estimate of the percent of the area of the image that is occupied by saltcedar can instantly be obtained by computer-assisted image analysis. Since the area of the image is known, an instant measure of the acres of saltcedar can be obtained. Since saltcedar occurs primarily

along streams, photographic flights along infested streams could measure nearly all the saltcedar and <sup>would</sup>~~could~~ not be prohibitively expensive.

Such measurements, done over time, could measure the changes in density and area infested and the effectiveness of various control programs, including biological control.

The distribution in Mexico was measured as a part of the present project and is reported separately as an appendix.

## V. BIOLOGY AND ECOLOGY

Saltcedars are halophilic shrubs or small trees that occupy disturbed fluvial channels throughout the western United States. A dense stand of saltcedar will grow only where the water table is between 1.5 and 6 m below the surface. If the water table is less than 1.5 m, the plant roots branch profusely below the surface and the plants do not form a dense stand (Campbell and Dick-Peddie 1964). When the water table is more than 6 m deep, saltcedar often forms an open shrubland with 15-20 ft between trees (Horton and Campbell 1974, Kerpez and Smith 1987).

The remainder of this section is taken from the dissertation of Stephens (1985, pp. 125-135).

### A. Growth Form

Considerable study of the growth forms of tamarisk has been undertaken because of its water consumption and propensity for choking stream channels. Wilkinson's (1966) summary of the subject seems most complete:

Morphologically, saltcedar appears to be a mesophyte adapted to a very narrow xeric ecosystem via (a) root penetration to a deep water source, (b) lowered water loss by reduced leaf area, (c) increased photosynthate production by cladophylls, and (d) development of salt glands which secrete the excess salt normally accumulated in plants growing on a hard water source. ~~Disturbed saltcedar is a small, gnarled tree. Disturbed saltcedar regrows by multiple shoots which arise from a burl or crown bud zone at (or near) the soil surface. Some new shoots arise each year, live a few years and die. Therefore, floodplain infestations of disturbed saltcedar become interwoven thickets.~~

*Smaller  
more*

In the Grand Canyon, several growth morphologies were apparent for tamarisk. Plants growing alone and undisturbed were rarely taller than 4 m and produced a spherical volume of foliage that extended to the ground. Plants growing alone but in disturbed settings (e.g., on cobble bars or bare

rock faces along the river) produced an exiguous growth and rarely exceeded 2 m in height.

Plants growing in close proximity displayed a markedly different morphology from those growing alone. Dense stands of tamarisk were comprised of tall (up to 11 m high), wand-like stems that supported little foliage and flowered only sporadically. Tamarisk growing in Grand Canyon is strongly affected by shading, and the interiors of dense tamarisk groves were extremely moribund, with an abundance of dead branches and litter. Self thinning is everywhere apparent in this species, both among individuals and in groves. Seedlings densities of more than 8000/m<sup>2</sup> were noted, while mature stands often supported fewer than one individual/m<sup>2</sup>. Foliage is restricted to the top of the canopy in mature stands, and leaf-area indices above 7.5 were determined by Davenport et al. (1978), with up to 98% of the leaves located in the top 1.0 m of the canopy. Incidentally, these researchers found that growth in groves reduces transpirational water losses in individual tamarisk plants, thus a "dense grove" growth strategy may confer extended survivorship in a desert environment. Tamarisk is said to be short lived (Read 1964), but no longevity data have been published and it is certain that tamarisk can live longer than 20 years.

According to Stephens (1985), Hayden (1976) cored tamarisk trees throughout the Grand Canyon to examine the condition of plants and the feasibility of control. He found older, senescent tamarisk on higher river terraces and noted that the health of tamarisk plants in the Grand Canyon declined with elevation and distance downstream from Glen Canyon Dam. He noted a lack of replacement in "senescent" stands. These observations were corroborated by Stephens (1985).

## 8. Flowers

At Cedar Bluff reservoir in Kansas, plants bloomed from late May through October, with peak anthesis in mid-August; all stages, from flower buds to mature seed, were often present on a plant at the same time (Merkel and Hopkins 1957).

Individual tamarisk flowers of I. chinensis and I. ramosissima are pentandrous and can produce ten seeds each. Flowers occur in loose clusters of racemes at branch tips and are white to pink in color. In extremely rare cases, tamarisk is able to flower after one year of growth and at one meter <sup>~</sup> height; however, it is more common to find flowering after two or more seasons of growth.

Small quantities of nectar are produced by the tiny tamarisk flowers, and the plant is largely or completely insect pollinated (Markgraf, pers. commu. 1977). The flowers are a source of nectar for honey bees although the honey produced is of inferior quality (see section XII, this report).

Using sweep net data, Stevens (1985) found that flowering tamarisk attracted a great abundance of potential pollinators, with six times the number of insects on blooming plants as compared to non-blooming plants in the Grand Canyon. He noted the abundance of calypterate muscoid Diptera and Hymenoptera in his study and noted heavy infestations of thrips. Insect species richness was also far greater on blooming plants. In part, the abundance of pollinators and foraging insects on blooming tamarisk is due to its flowering phenology: it blooms from mid-spring after the early spring bloom of native species has subsided and <sup>~</sup> though August before the late summer bloom of native species has begun. Tamarisk, therefore, provides resources at times when few native species are blooming.

### C. Seeds

Tamarisk produces phenomenal quantities of short-lived, wind-dispersed seeds. In central Arizona, Tamarix produce seeds in two peaks, one in late spring and one in August (Warren and Turner 1975). Small plants produced more than 600,000 seeds in a single reproductive cycle (Bowser 1957). Flowering in the Grand Canyon was dependent on shading and proximity to other shrubs. Plants in dense groves produced fewer than 50,000 seeds in May 1983 while several 3.5-meter-high plants in open settings were estimated to bear more than 100,000,000 seeds in one reproductive bout. This may be the largest number of seeds <sup>recorded</sup> ~~produced~~ by a higher plant at one time.

Seed germinated throughout the growing season, but viability increased from 19% in June to a maximum of 51% in August and declined to 27% in November. By the next June, 50% were still viable if stored at 10°C but none were viable <sup>with this</sup> when stored at room temperature. After being wet, 57% of the seed germinated ~~in~~ 24 hrs.

### D. Germination and Establishment

Tamarisk seeds bear abundant pappus hairs that enable the seeds to be carried long distances by the wind, ~~and~~ seeds must land in water or on a moist substrate <sup>to germinate.</sup> The pappus hairs and seed coat are shed as little as eight hours after the seed is moistened and the entire process of tamarisk germination takes less than 24 hours (Horton et al. 1960).

Tamarisk seeds often germinate as flood or reservoir waters recede, and silt bars and beach face become "green lawns" of tamarisk seedlings. Following the spillover discharge flood in 1980, tamarisk seedling densities exceeded 8000/m<sup>2</sup>, and Warren and Turner (1975) found seedling densities of up to 17/cm<sup>2</sup> (170,000/m<sup>2</sup>) on a central Arizona reservoir mud flat.

The roots of in order to continue growth,  
 A tamarisk seedling's roots must reach a sufficiently moist and protected edaphic environment before the surface crust of silt dries ~~out~~. Several edaphic studies in the Grand Canyon have shown that tamarisk most commonly ~~takes~~ <sup>s</sup> root <sup>λ</sup> in interbedded, eroding laminae of pre-dam sandy silt and silty sand depots that have a high moisture retention capacity (Harrison 1981, Scala 1984, Stevens 1985).

Stevens (1985) observed that, in the Grand Canyon, successful tamarisk germination and seedling establishment required moist, fine silt deposits which result from flooding events. Other researchers have also drawn this same conclusion (Horton et al. 1960, Tomanek and Ziegler 1962, Potter and Pattison 1976, Irvine and West 1979). Flood-linked establishment is also indicated by the consistency of stem ages in stands on different flood terraces above the river (Hayden 1976). At Nankoweap Canyon in the Grand Canyon (Mile 53), the highest terrace was colonized in 1957 (the last pre-dam, ten-year flood), a middle terrace was colonized in 1962, and the riverside terrace was colonized <sup>in</sup> <sup>λ</sup> about 1970.

Hayden (1976) noted that the fine silt deposits necessary for tamarisk establishment were most often encountered on the crests of the newly deposited riverside terraces. In the course of this study, his observations were corroborated and other appropriate germination settings were also found. The silt deposits left by flash floods from tributary canyons and the micro-deposits of silt left on the upstream faces of stones in cobble bars were environments particularly suited to tamarisk germination.

Edaphic changes resulting from impoundment have resulted in beaches predominantly composed of sand, rather than silt and clay, particles. These larger particle sands ~~wick moisture and dehydrate~~ <sup>dry</sup> too rapidly to permit tamarisk seedlings (<sup>or</sup> ~~and~~ other species) to germinate successfully. Horton

et al. (1960) found that tamarisk seedlings and young plants die after two days of drought and <sup>were</sup> ~~are~~ not as tolerant of desiccation as <sup>were</sup> ~~are~~ native riparian shrub species, such as ~~the~~ Baccharis seepwillow. These researchers also found that tamarisk seeds remained viable for only a few weeks when subjected to natural desert conditions but that seed viability could be extended up to 47 weeks with laboratory refrigeration.

The ultimate survivorship of tamarisk seedlings in the post-dam Grand Canyon riverside environment is extremely poor. None of the more than 20,000 tamarisk seedlings located in 1980 survived more than three years, with most mortality due to desiccation and erosional disturbance. *ref?*

Hopkins and Tomanek (1957) found that saltcedar seed germinated to produce thick stands in the mud zone when flood waters receded. One-meter quadrats averaged 897 seedlings on July 9; 72% of these died during the first year and survival for the whole year was less than 10%. They speculated that if the water level fluctuated so that seedlings were totally submerged, then allowed to dry, the plants might never develop beyond the seedling stage.

#### E. Leaves

The foliage structure of tamarisk is comprised of cladodes, deciduous cladophylls (cylindrical leaf-like branches) which bear two sizes of whorled, subulate, sessile, slightly clasping leaves. The scalelike leaves may attain a length of 3 mm, whereas the cauline leaves vary in length up to 8 or 9 mm (Wilkinson 1966c). These leaves comprise less than 50% of the photosynthetic material of tamarisk, the rest being cladophyll stems. <sup>The density of</sup> ~~Stomates were found~~ to occur at an average <sup>density of</sup> ~~density of~~ 5045/cm<sup>2</sup> over the entire photosynthetic surface ~~by~~ (Davenport et al. (1978)).

Bud break in Grand Canyon tamarisk occurred in late March or early April with leaf fall in late October. Wilkinson (1966) found a single growth of

foliage through the growing season; however, plants in the Grand Canyon produced a conspicuous second growth of vegetation in July following initiation of the summer monsoons (Stevens 1985). Premature chlorosis of tamarisk occurred in August, especially among plants that ~~stood away~~ <sup>growing away</sup> from the river bank and in high-water years. Factors responsible for premature chlorosis in Grand Canyon tamarisk remain unexplained but may be related to invertebrate herbivory or some form of moisture stress.

#### F. Roots

The root structure of Tamarix is characteristically deep and extensively branched, with a maximum recorded depth of 30 m in the Suez Canal Zone (Robinson 1958). Horton et al. (1960) found that tamarisk root length generally exceeds shoot length in seedlings after seven weeks of age. Roots grew slowly at first but at 10 weeks had reached 30 inches; one 3-year-old plant had roots 10 ft. long on 3 sides and 19 ft. long on one side; most lateral roots were 12-16 in. deep but the primary root was more than 16 ft. deep (Merkel and Hopkins 1957).

Development of the root system is highly variable, depending on depth to the water table and soil type. In a windbreak where the water table was 26 ft deep, roots spread laterally 30 ft with most <sup>occurring</sup> in the top 12 to 16 in. of soil; however, primary roots extended below 16 ft (Merkle and Hopkins 1957). Roots growing downward through sand or gravel tended to spread horizontally when they encountered a clay layer, although some penetrated the clay. Radial or horizontal spread of the roots was limited mostly to areas immediately above the groundwater table and in the capillary fringe, although some functioning roots extended more than 2 ft into the water table (Gary 1963). In the greenhouse, most of the roots died if submerged with subsequent poor aeration (Merkle and Hopkins 1957). However, Gary (1963),

based on field observations, speculated that the root systems of mature trees apparently are capable of surviving long periods of complete soil saturation, although plants in general can survive only short periods of complete inundation.

In addition to normal root growth, the stems produce adventitious roots if flooded or if covered with moist soil. If plants are covered with silt during flooding, layering occurs and the buried stems produced new shoots.

Wilkinson (1966b) found that plants produced adventitious roots endogenously near the vascular cambium. Both he and Ginzburg (1967) commented on the plant's ability to grow by layering. When branches are buried by fluvial or eolian deposits, they root adventitiously and sprout up in a form of vegetative propagation akin to clonal growth. Layering has been observed in the Grand Canyon but it is a relatively unsuccessful strategy there because of nearly continuous fluvial erosion. Ando (1980) found that only 17% of the tamarisk stems he planted in an irrigated field survived. Gary and Horton (1965) found that 100% of stem cuttings sprouted at all times of the year if they were kept moist and warm, but root cuttings did not sprout; if stem cuttings were allowed to dry, even for only one day, sprouting was greatly reduced. However, Wilkinson (1966a), using stem cuttings, obtained 70-100% rooting and 96-100% shoot formation except during two dormant periods during June-July and October-November when shoot formation was only 15-60%. Wilkinson (1966b) obtained rooting in 8-21% of root cuttings buried in soil in the greenhouse. Stem elongation was maximal at a 14-hr photoperiod; stem growth increased from October through the winter and spring, peaked in early May, then declined rapidly to September (Wilkinson 1966c,d).

## G. Inundation and Desiccation Stress

Tamarisk is extraordinarily tolerant of inundation, a trait which permits ~~this species~~ <sup>it</sup> to colonize streamside habitats and the sediments flats at the heads of reservoirs. Horton et al. (1960) found that tamarisk seedlings were able to survive total inundation for up to four weeks, but after <sup>one</sup> ~~a month~~ mortality increased sharply. Horton's group also found that young seedlings were readily uprooted even in still water and that seedlings 12 weeks or older resisted uprooting and drowning better than did younger plants.

Warren and Turner (1975) measured mortality of 576 saltcedar plants growing along the shore of the San Carlos Reservoir, AZ, as the lake level rose and subsided ca. 12 ft during 1966 and 1967. Mortality was influenced mainly by the interaction of the duration of submergence of the root crown and that of the entire aerial part (shoot) of the plants. One of 7 trees died when the root crown was submerged for 71 days, mortality increased greatly with 81 or 90 days submergence, and all but 1 of 248 trees died when submerged 98 or 107 days. At 81 and 90 days root crown submergence, mortality increased steadily as progressively more of the shoots were also submerged, from no mortality of 5 trees that had 5 or 6 ft of the shoot exposed to 92% of 290 trees that had only 1 ft or less of the shoot exposed. All of 240 trees observed died when the root crown was submerged 98 or 107 days and the shoots were completely submerged for 43 days (the minimum complete submergence observed).

In the Grand Canyon below Glen Canyon Dam, the flood of 1983-84 peaked at 2621 m<sup>3</sup>/sec and inundated the zones nearest the river from late spring 1983 through 1984 (Stephens and Waring 1985). In the 700-1700 m<sup>3</sup>/sec flood zone, 44.8% of the Tamarix was killed (30.4% by removal and 20.7% by drowning). Other deep tap-rooted species (Prosopis glandulosa and Acacia

gregii) had similar mortalities. Clonal, shallow-rooted and other shallow-rooted species suffered higher mortalities. Nevertheless, the overall immediate effects were moderate and the flood produced only a "weeding" or decrease in overall plant density, and the riparian species persisted. Dense colonies of Tamarix seedlings appeared beneath the canopy of flooded older Tamarix, <sup>a situation</sup> which had never been seen before, while no seedlings appeared beneath the canopies of Tamarix not inundated (Stephens and Waring 1985).

#### H. Salt

Several workers have elucidated aspects of salt excretion in the genus Tamarix. Davenport et al. (1978) found that New Mexican tamarisk contained an average of 1858 eight-celled salt glands/cm<sup>2</sup> imbedded in epidermal pits in the leaves and cladophylls. These salt glands excrete excess salt and enable tamarisk to tolerate extremely saline conditions. Some authors consider this species salt tolerance limit to be 10,000 ppm (Mark and Peterson 1962); however, tamarisk has been observed growing in parts of Death Valley, California, where salt concentrations reach 50,000 ppm (Robinson 1965). Waisel (1961b), Hem (1967), and Berry (1970) found that ~~this species~~ <sup>Tamarix</sup> excrete <sup>5</sup>chlorine, carbonates, sodium, potassium, bromine, calcium, nitrate, magnesium, and sulfate in considerable quantities. Hem (1967) observed that these ions comprised 5% to 15% of the dry weight of the leaves and that as much as 3% of the dry weight of the leaves could be washed off during rain storms as ions. The latter author found that phosphorus (PO<sub>4</sub>) was not excreted by Tamarix aphylla. all authors agree that the differential excretion by Tamarix is dependent on the ionic composition of the substrate on which it is growing.

The hypothesis that tamarisk salt excretions serve as haline allelopathic agents that prevent understory invasion was tested by analyzing riparian soils (Scala 1984). Only potassium was shown to accumulate anomalously at the soil surface beneath tamarisk plants. The role of potassium in allelopathy is not known.

#### I. Secondary Chemical Compounds

Besides salt-related research, little work on secondary compounds in Tamarix has appeared in the literature. In a study of chemical taxonomy, Harborne (1975) found five Tamarix species, including T. gallica, to contain flavenol bisulphates and bisulphate-glucuronides. Likewise, Nawwar et al. (1977) found unusual flavonoid sulphates in members of the Tamaricaceae<sup>e</sup>. The chemical constituents of tamarisk resins and the possible occurrence of phenols, tannins, or other anti-herbivore chemical defenses have yet to be adduced.

## VI. DISPLACEMENT OF NATIVE VEGETATION

### A. Historical Perspective and Present Status

Significant impact caused by man on riparian systems began 450 years ago when the Spanish explorers introduced grazing livestock. The rate of impact has increased rapidly during the last 100 years due to cutting trees for firewood, land clearing for agriculture, dam construction, <sup>channelizing of streams,</sup> livestock grazing, pumping of groundwater for irrigation, and increased recreational pressures. Except for some concern about the impact of these actions on hunting, little consideration was given to the value of riparian areas as natural plant communities and as home for wildlife in addition to game birds and animals (Davis 1977).

Until the 1960's, riparian areas were viewed only for their consumptive value and <sup>potential</sup> economic gain (Carothers 1977, Davis 1977, Kennedy 1977). The major effort was aimed at 1) salvaging water for agricultural irrigation and municipal use and 2) flood control by building dams, removing phreatophytic plants, and channeling the streams; and 3) clearing land for agriculture and ~~using the areas for~~ livestock grazing. Riparian zones are areas with maximum conflicts of usage and the consequences of managing for maximum water yield, livestock production, or wildlife are very different (Davis 1977).

During the 1960's, with the beginning of ~~the great~~ public concern over environmental quality, pesticide pollution, etc., the various agencies responsible for management of southwestern riparian areas and water resources began taking the broader view of management for multiuse objectives (Horton 1976 and others). This view was spurred on in the 1970's as the newly created Environmental Protection Agency began requiring environmental impact statements and mitigation of damage produced before projects could proceed.

Action taken by various environmentally oriented organizations blocked, through court injunctions, further phreatophyte clearing and channelization projects until those requirements were met (Hildebrandt and Ohmart 1982, pg. 2).

The "original" flood-plain vegetation along many of the streams in the arid southwestern U.S., especially in Arizona, was comprised of forests of cottonwood and willow; thickets of seepwillow, arrowweed, and seepweed; and low woodlands of mesquite. These areas were inherently unstable, even without the influence of man, and were periodically altered at irregular intervals by large floods that caused inundation, drowning, and washing out of the soil, trees and other vegetation; erosion; and deposition of sediment, later followed by natural revegetation and regrowth of the same species. Although unstable, the pattern of change fell within well-defined limits (Turner 1974) and was termed perpetual succession by Campbell and Green (1968).

1. Lower Colorado River.--Ohmart et al. (1977) described the demise of the cottonwood forests along a 275-mile stretch of the Lower Colorado River from Davis Dam to the Mexican boundary; 75 miles is through canyons, leaving 200 miles of suitable habitat for cottonwood. This area in the late 1970's contained 111,692 acres of riparian vegetation (Anderson and Ohmart 1984b). Ohmart et al. (1977) calculated that a minimum of 5,000 acres of cottonwood originally grew in this area, allowing 100 ft of cottonwood on each side of the river. This figure appears too low even as a minimum. Cottonwood Island (4-6 mi long X 3/4 mi wide), Cottonwood Valley (5-6 mi long) and a river bend he reconstructed from original surveys (his Fig. 1) could total 7,000 acres. The early explorers wrote of the vegetation being 1-2 miles wide in places but this consisted of mixed cottonwood, willow, mesquite,

screwbean, arrowweed, and other plants. The original amount of cottonwood was probably nearer 10,000 acres. In 1972, only 2,800 acres of cottonwood-willow remained, and less than 500 acres was pure cottonwood (Ohmart et al. 1977). The last large stand (ca. 290 acres) of cottonwood along the Lower Colorado is on the Bill Williams River near Lake Havasu (Hunter 1984).

The cottonwoods regrew twice--once after the steamboat operation ceased about 1890 and again after the floods of 1905 and 1907 (Turner 1974). The rapid growth of saltcedar began about the time the dams were built. Much of this area is now occupied by dense saltcedar. Cottonwood appears able to maintain dominance over saltcedar in some areas (the upper Rio Grande in New Mexico, the Verde River in Arizona); but on the Lower Colorado, Ohmart et al. (1977) questioned whether it would have withstood the invasion even without the dams. On areas of the Gila River, saltcedar replaced the native species without the influence of dams (Turner 1974).

Along the Colorado River (a 286-mile reach between Glen Canyon dam and Lake Mead that includes the Grand Canyon), a comparison of 73 old photographs made between 1872 and 1963 with photographs of the same sites made between 1972 and 1976 after construction of Glen Canyon Dam shows great changes in vegetation (Turner and Karpiscak 1980). The older photographs show an absence of riparian plants along the river, caused by the scouring action of frequent floods. The new photos of each pair show greatly increased density of many plant species. Exotic species, such as saltcedar and camelthorn, and native plants such as sandbar willow, arrowweed, desert broom, and cattail, now form a new riparian community along much of the channel. The photos and detailed maps of the distribution of 25 plant species show that saltcedar occurs almost continuously along the river. Other plants of greater wildlife value, such as sandbar and Goodding willow, western honey

mesquite, catclaw, Fremont cottonwood, hackberry, and other shrubs, now occur commonly in many areas.

Hunter (1984) reported that the riparian vegetation of the Lower Colorado River Valley in the late 1970's from Davis Dam <sup>W.D.D.</sup> on the Arizona-Nevada border to the Mexican border consisted of 54% saltcedar and 33% of all vegetation was SC-IV (canopy layer at 3.0-4.5 m). Relatively mature native vegetation (cottonwood-willow, western honey mesquite, screwbean mesquite) comprised very little of the vegetation: none in Structural Type I (6 m or taller), 0.58% in Type II (one vegetation layer at 6.0 m or taller), and 3.85% in Type III (4.5 to 6.0 m).

A more accurate vegetational survey was made of the Lower Colorado from Davis Dam to the U.S.-Mexican border by Younker and Anderson (1986). They classified 5,754 acres (5.35%) of the total 107,649 acres in the survey area as cottonwood-willow (defined as at least 10% of the trees being cottonwood-willow). A total of 45,037 acres was classified as saltcedar (80-100% saltcedar) or 41.8% of the total area (Table 1). However, substantial amounts of other classifications also consisted of saltcedar.

If we assume that saltcedar constituted 50% of the cottonwood-willow and of ~~the~~ saltcedar-screwbean mesquite areas, and <sup>60</sup>~~70%~~ of the saltcedar-honey mesquite area, then the total area in saltcedar would be <sup>52,550</sup>~~61,176~~ acres, or <sup>56.3</sup>~~56.8~~% of the total area (Table 1). Honey mesquite, <sup>could be 14,483</sup> screwbean mesquite, <sup>7.2%</sup>

<sup>0.01</sup> arrowweed and marsh made up most of the rest (Table 2). Only 0.51% of the area (544 acres) was classified as the taller structural Types I and II and only 1.85% (1990 acres) as Type III that are favored by many species of birds and Type II that is preferred by the white-winged dove (see Sect. <sup>VII</sup>~~A~~, 0,3 of this report). All of this Type I Tamarix was athel.



Table 1. Vegetative composition of various riparian areas of which measurements have been made.

Location and Reference	Total area vegeta- tion (acres)	Cotton- wood willow	Honey mesquite	Screw- bean mesquite	Salt- cedar	% Sa ce
Lower Colorado, AZ & CA (Yunker and Anderson 1986)	107,649	2,877 <sup>a/</sup> 2,298	11,581 10,888	7,746 <sup>a/</sup> 7,278	61,176 <sup>a/</sup> 56,881	5
Rio Grande, western TX (Engle-Wilson and Ohmart 1978a)	1,610					4
Pecos, Santa Rosa, NM to Gervin, TX (Hildebrandt and Ohmart 1982)					27,788	9
Rio Grande, Santa Fe to Socorro, NM (Hink and Ohmart 1984)						
Middle Rio Grande (Campbell and Dick-Peddie 1964)						
Lower Gila, AZ (Haase 1972)	16,356					5
Middle Gila, AZ (Turner 1974; Gatewood 1950)						
Colorado, TX (Larner et al. 1974)	8,359	192	4,333		3,834	4
Bighorn, <sup>WY</sup> <del>MT</del> (Akashi 1988)	ca. 630				ca. 345	5
Yellowstone, MT (Swenson et al. 1982)						
Brazos, TX (Busby and Schuster 1973)	62,580	4,477	19,202	0	35,266	6
Utah (Christensen 1962)						

<sup>a/</sup> Cottonwood willow = at least 10% CW, honey mesquite - 90-100% mesquite  
screwbean mesquite = at least 10% screwbean, applicable to the Lower Colorado only.

Table 2. Classification of vegetative along the Lower Colorado River from Davis Dam to the U.S.-Mexican border (from Younger and Anderson 1986).

Community type <sup>a/</sup>	Acres in each structural type <sup>b/</sup>						Total	%	
	I	II	III	IV	V	VI			
CW		225	502	1,733	2,867	427	5,754	5.35	2.61
SC	310	9	11	22,381	17,560	4,766	45,037	41.84	55.3
HM	96	103	1,089	8,889	1,583	20	11,581	10.76	14.4
SM			360	7,825	7,067	240	15,492	14.39	7.2
SH			28	5,966	1,879	7	7,880	7.32	
AW						7,478	7,478	6.95	
ATX						1,231	1,231	1.14	
IW						221	221	.20	
Marsh 1-6						10,812	10,812	10.04	
Marsh 7						1,737	1,737	1.61	
CR					426		426	.40	
Total	310	234	1,990	46,794	31,382	26,939	107,649		
%	0.29	0.22	1.85	43.47	29.15	25.02		100.00	

<sup>a/</sup> Structural type

% of foliage density at height:

	0-2 ft	2-15 ft	>15 ft
I	24	30	46
II	13	33	54
III	29	53	25
IV	38	46	18
V	58	36	6
VI	69	24	5

See also Section VII,A,2 and Fig. 10.

<sup>b/</sup> CW=at least 10% cottonwood and willow; SC=80-100% saltcedar; SH=saltcedar: honey mesquite (mesquite at least 10% but rarely more than 40%); SM=saltcedar:screwbean mesquite (at least 20% screwbean); HM=90-100% honey mesquite; AW=90-100% arrowweed; ATX=90-100% is 3 species of Atriplex; MA=marsh, mostly cattail and bulrush; CR=90-100% creosotebush.

SC = 55,550

pg 104 says 20%

2. Gila River.--Turner (1974) documented vegetation and channel changes along a 15-mile reach of the Gila River from Bylas to the confluence of the San Carlos River, ~~the study area of the Gila River Phreatophyte Project, from 1914 to 1964~~ <sup>from ~~was~~ this was the</sup> Early records indicate a narrow channel in 1875 that probably was greatly widened by the large flood of 1881, after which it narrowed again. The very large floods of 1905 and 1906 widened the channel from an average of 48.7 m to 588.3 m in one section; channel area increased from 89 to 1207 ha and vegetative cover was reduced from 1118 ha to none (Burkham 1972, Turner 1974, Minckley and Clark 1984). The channel remained wide through 1935 but narrowed rapidly from 1937 to 1947 and has remained narrow since. Early records indicate that a narrow strip of willow <sup>(ca. 10 yd wide)</sup> bordered the stream, ~~about 10 yd deep~~, then cottonwoods up to 2-3 ft diam extended in a strip 200-300 yd <sup>wide</sup> ~~deep~~ (Turner 1974); other records refer to dense stands of mesquite. Cultivation began in the area in the early 1870's.

Vegetation changes since 1914 have been dramatic (Fig. 9). The area was dominated by mesquite, seepwillow and some cottonwood in 1914. The situation was not much changed by 1937, although saltcedar had invaded and occupied 59 ha. The water level in the San Carlos reservoir rose in 1932 and 1933 to 32 ft and 19 ft, respectively, above the forest floor and killed all the cottonwood trees on the western end of the area; much of the flooded area was then invaded by saltcedar. Additional cottonwoods were killed in 1941-42 when the reservoir reached a record level and flooded much of the area for almost 2 years.

The 1964 map shows that saltcedar then occupied the entire shoreline of the river and almost the entire floodplain in the western 40% of the area (407 ha infested), much of it in dense stands. Cottonwood was ~~completely~~ <sup>absent</sup> ~~except for a few scattered trees and there was no seepwillow~~ <sup>remained</sup> The area



in mesquite remained approximately the same in 1964 as in 1914. When examined in 1964, no living cottonwood tree had become established since 1932 and the oldest was 67 years old (established in 1897). Reestablishment of cottonwood, then, ceased at about the time saltcedar invaded. Saltcedar appears capable of maintaining its hold on the invaded area indefinitely (Turner 1974), a drastic change from the previous state of perpetual succession.

Great thickets, or bosques, of mesquite formerly grew in many riparian areas such as the San Xavier thicket on the Santa Cruz River just south of Tucson, the Komatke thicket on the Gila River near Phoenix, thickets in the Arlington-Buckeye area just west of Phoenix, and Texas Hill on the lower Gila. Many thickets had been destroyed by 1925. The San Xavier and Komatke thickets were declining by the 1960's, causing a severe drop in the white-winged dove population (Wigal 1973). By 1973, these and the Texas Hill bosques <sup>had disappeared,</sup> ~~were gone,~~ killed by lowered water tables, changed seasonal flow of the rivers, and cutting for firewood (Brown 1973). Today, only remnants remain on the San Pedro, Santa Maria and Verde Rivers, at Robbins Butte and a few other sites (Brown et al. 1977b, Fox 1977). Saltcedar invaded in the 1930's and by the 1960's had replaced much of the former mesquite and cottonwood forests, and had become the principal white-winged dove habitat in many areas. Phreatophyte clearing projects have now destroyed much of that area. The last big stand of velvet mesquite suitable as habitat for the large colonies of whitewings (trees 30 ft tall and 100% canopy cover) is along the Gila River between the Highway 85 bridge and Gillespie dam (AG&FD, January 1989, pers. comm.).

Minckley and Clark (1984) monitored the progressive destruction of a dense, mature mesquite bosque of ca. 10 ha on an uncontrolled (no dams

7 use on not?  
upstream) area of the Gila River near Safford, AZ. This was within or near the area described above by Turner (1974). The floods of 1972 began eroding the bosque. In March 1978, another 1.5 ha disappeared, and in Dec-Jan 1978-79, an additional 3.5 ha disappeared. These winter floods also deposited up to 0.5 m of silt within the remaining bosque and 1 m <sup>in the area</sup> across the river. By the summer of 1982, mesquite seedlings were again established on these new silt deposits.

Brady et al. (1985) followed the development of gallery forests (cottonwood, willow, mesquite, saltcedar, and other species) along the Gila River near Cliff, NM, and along the San Pedro River, AZ; both are "uncontrolled" rivers. They found that light or moderate flooding favored establishment and development but that major flooding was always catastrophic. The effects of different types of reservoirs on vegetation may be very different. Szaro and DeBano (1985) stated that the small flood-control Whitlow Ranch Dam on Queen Creek, Pinal County, AZ, improved riparian habitat by allowing willow establishment because the reservoir held water for only a short time after storms. Still, most of the vegetation was saltcedar.

In the Lower Gila River Valley along a 58-mile stretch east of Yuma, saltcedar occupied over 50% of the 6622 ha (16,356 acres) of vegetation surveyed. Although more than half of the Tamarix was more than 3 m high, trees over 8 m (good nesting trees for whitewings) were uncommon (Haase 1972).

3. Rio Grande.--On the Rio Grande between Ft. Quitman and Haciendita, TX, Engle-Wilson and Ohmart (1978a) (Table 1) evaluated the effects on vegetation and wildlife of three management alternatives for marking the boundary between the U.S. and Mexico. They determined that sufficient saltcedar was available for doves and additional saltcedar was not needed.

However, under the "no-action" option, saltcedar would continue increasing and cottonwood-willow would decrease. They concluded that Option 1 (channeling and clearing an overflow-channel on both sides of the river and periodic mowing) could be beneficial to wildlife IF the proper management practices were used. These would include 1) planting the spoil mounds to grass, forbs and shrubs, 2) delaying annual mowing of the overflow channels until late winter and mowing at least 1 ft high to leave cover for rabbits and rodents, 3) allowing some farming, which would provide grain for wildlife, and 4) clearing saltcedar carefully to leave the cottonwoods, willows, seepwillow, and other shrubs, while planting cottonwoods where none existed.

Along the Rio Grande in Big Bend National Park, TX, Denyes (1956) recognized three plant associations: 1) riverbank (honey mesquite, seepwillow baccharis, Goodding willow, or cottonwood); 2) dense stands of seepwillow baccharis; and 3) mesquite. By 1976, Boer and Schmidly (1977) recognized major changes, especially the tremendous increase in saltcedar. The baccharis association that previously was common was recognizable only at a few places and had largely been replaced by a mixed mesquite-saltcedar-bermudagrass association; also, saltcedar was replacing the cottonwood and willow trees at many places.

Campbell and Dick-Peddie (1964) found that <sup>the area occupied by</sup> saltcedar decreased ~~in density~~ along the Rio Grande from 39% near El Paso to only 2% near Albuquerque, while <sup>area in</sup> cottonwood increased ~~in density~~ from 6% to 73%. Hink and Ohmart (1984) described the vegetational changes on the Middle Rio Grande from Espanola to San Acacia, NM.

4. Brazos River, TX.--Busby and Schuster (1973) measured the different vegetation types along the Brazos River, TX, from Possum Kingdom Lake to the headwaters, from aerial photographs made in 1940, 1950 and 1963-68. ~~At~~ this

*area contained*  
~~area~~ of 62,580 acres of riparian vegetation, saltcedar-dominated communities

comprised 56.4%, mesquite 30.7%, cottonwood 7.2%, and other vegetation 5.7% (Tables 1,3). Between 1940 and 1969, saltcedar had increased by 52.5% while the area in the riverbed and sandbars had decreased by 47.4% (Table 4).

5. Other Regions.--Saltcedar apparently is invading more northern areas in the same manner as in the southwestern U.S.--only the invasion has occurred later, is not <sup>occurring in</sup> ~~tied to~~ areas of <sup>serious</sup> ~~desperate~~ water shortage, and, ~~is~~ <sup>therefore</sup> ~~is~~ less well documented.

Akashi (1988) studied the riparian vegetation dynamics in a 536-ha (1324-acre) site at an elevation of 1114 m (3660 ft) along the Bighorn River, WY, just south of the Montana border. In a thorough survey made in 1954, no saltcedar was found. Between 1954 and 1960, 6 major fires burned the woodland. In 1961, saltcedar was first found, restricted to sandbar meadows and very young woodland and occupying only a few acres. From 1961-1967, it invaded many of the native shrublands, and by 1967, it occupied 113 acres in mixed and 43 acres in pure stands. By 1981, it occupied 172 acres in mixed and 137 acres in pure stands, or <sup>an area</sup> ~~an area~~ almost equal to the area of native shrublands (Table 1). During this time, the amount of Rhus decreased from 199 acres to 102 acres. By 1986, saltcedar-associated areas occupied ca. 55% of the vegetated areas. Akashi found that saltcedar on terraces higher than 2.5 m above river level appeared to be dying. The pattern of saltcedar establishment on the floodplain in 1968 was strikingly similar to the area inundated in the flood of 1963.

#### B. Causes of Riparian Habitat Degradation

A detailed examination of the causes of the degradation of riparian ecosystems in semi-arid southwestern North America is beyond the scope of this report. However, the major contributing factors are discussed briefly

Table 3. Vegetation of the Brazos River and major tributaries in northwestern Texas (from Busby and Schuster 1973).

Vegetative community	Acres of vegetation			Total	% of total
	Brazos River	Salt Fork	Double Mt. Fork		
Saltcedar dominated	(17,199)	( 9,429)	( 8,638)	(35,266)	(56.4)
Saltcedar alone	13,216	8,706	7,045	28,967	46.3
Saltcedar-baccharis	2,527	723	1,593	4,843	7.7
Saltcedar-mesquite	1,456	0	0	1,456	2.3
Mesquite dominated	( 8,079)	( 5,675)	( 5,448)	(19,202)	(30.7)
Mesquite alone		5,471	4,706		
Mesquite-saltcedar		94	73		
Mesquite-sand sagebrush		110	669		
Cottonwood dominated	( 1,981)	(203)	(2,293)	(4,477)	(7.2)
Cottonwood alone	588	177	924	1,689	2.7
Cottonwood-saltcedar	411	21	1,107	1,539	2.5
Cottonwood-mesquite	982	5	262	1,249	2.0
Sand sagebrush		(184)	(61)	(245)	(0.4)
Other mixed	<u>(3,370)</u>	<u>(0)</u>	<u>(20)</u>	<u>(3,327)</u>	<u>(5.3)</u>
Total vegetation	30,629	15,491	16,460	62,580	100.0
Cultivated	10,288				
River bed	7,199	6,188	9,315		

Table 4. Changes in vegetative composition of the floodplain of the Brazos River, TX, 1940-1969 (from Busby and Schuster 1973).

Vegetation type	Vegetation (acres)			% change from 1940-69
	1940	1950	1969	
Saltcedar	4,746	6,891	7,237	+52.5
Mesquite	4,352	4,872	5,112	+17.5
Cultivated	5,100	5,394	5,886	+15.4
Grassland	762	372	0	
Sand bar	2,154	552	0	
River bed	5,080	3,806	3,808	
Sand bar + riverbed	(7,234)	(4,358)	(3,808)	-47.4

to illustrate the complexity of the causes and of the solutions that must be considered, how biological control of saltcedar would improve the situation and how it would interact with the other causes.

The impact of man's activities since the mid-1800's has drastically altered the natural situation. The principal causes are (Davis 1977):

- a) Overgrazing by livestock
- b) Clearing land for agriculture
- c) Cutting trees for firewood or building materials
- d) Construction of dams for flood control and irrigation
- e) Urbanization and housing developments and recreation
- f) Improper pumping of groundwater for irrigation and municipal use with consequent lowering of water tables and cessation of stream flow
- g) Clearing phreatophytes and channelization
- h) The introduction, escape and naturalization of exotic plants such as saltcedar and Russian olive
- i) Fire

The consequences of these activities have had a devastating effect on the plant communities and the wildlife that depend on these areas. These

problems have been addressed in several national--and regional symposia-- (Johnson and Jones 1977, Johnson and McCormick 1978, Swanson 1979, Johnson et al. 1985). The position of various government<sup>al</sup> agencies toward riparian ecosystems was explained by Almand and Krohn (1978) for the Bureau of Land Management, by Barry (1978) for the Soil Conservation Service, by Davis (1978) for the Environmental Protection Agency, by Hirsch and Segelquist (1978) and Spear (1985) for the Fish and Wildlife Service, by McGuire (1978) for the Forest Service, and by Jones et al. (1978) for the Bureau of Reclamation.

A number of recommendations have been made for research needs (Patton 1977, Brown et al. 1977b, Kerpez and Smith 1987, Bennett and Burke 1989) and for coordinating the management of riparian areas for multi-use objectives (Johnson et al. 1977, Behnke and Raleigh 1978, Brown et al. 1977b). Kusler (1978) pointed out the need for coordination of intergovernmental programs. McCormick (1978) discussed the proposed National Riparian Program prepared by USDI. In the late 1970's, several new federal programs, such as Unique Ecosystems, National Heritage, and National Wild and Scenic Rivers, provided powerful tools for improving riparian ecology (Herbst 1978). Odum (1978) noted that the market system, chief "forcing function" in today's decision making<sup>process</sup>, generally favors development for private gain above the public good. He argued that preservation should be based on public as well as private riparian rights and that riparian areas should be regarded as natural resources as are navigable streams, to provide an effective hedge against overdevelopment of urban sprawl and agricultural or forest monoculture.

King and Charbonneau (1978) showed that the "energy approach" to valuation of riparian habitats was totally lacking in utility to society in making judgments. The "economic approach" also was somewhat lacking in

ability to identify correct social decisions. They recommended a system of accounts:

- 1) Economic
- 2) Ecological
- 3) Various social measures, and
- 4) Political, such as impacts on local constituents.

The "Habitat Evaluation Procedure" employed by the Fish and Wildlife Service serves well for ecologically analyzing what is on the ground, but a more holistic measure is also needed.

1. Livestock Overgrazing.--One of the greatest and most insidious threats to riparian regeneration is livestock grazing (Carothers 1977, Ames 1977). Cattle have a strong preference for riparian areas. The grass and forbs there are more succulent and palatable, and they find shade from the summer sun and protection from winter winds. If allowed, they will use these areas continuously. During the late 1800's, ranchers greatly increased stocking rates. Cattle ate the seedlings and alders and willows were eliminated, leaving only bermudagrass and unpalatable trees such as seepwillow, desert willow and saltcedar. After 50-100 years of free-choice grazing and no regeneration, even the mature cottonwoods and willows were dying (Kennedy 1977, Bergthold 1978). Reproduction by cottonwoods is reduced to almost zero with grazing (Glinski 1977). <sup>Every</sup> ~~However, only~~ a few days grazing seriously impairs reproduction of riparian areas. Ames (1977) concluded that no system of management that includes livestock adequately protects riparian areas--even short-term or seasonal use is damaging. The only acceptable management system is to fence livestock out permanently, leaving places for them to get to water. From the point of view of best utilization for grazing, Schrader (1977) recommended that only areas with a water table of less than 8 ft should be grazed, where saltgrass and

bermudagrass grow well. If cattle are fenced out, the streamside vegetation goes through successional stages which White and Brynildson (1967) and Kennedy (1977) described, to a more stable condition. The stream channel narrows and deepens, more vegetation grows, silt banks are stabilized and the water is cooler and contains less sediment. However, after 20 years or more, some trees die and fall into the stream channel, <sup>and</sup> the dense shade reduces vegetation on the banks.

Behnke and Raleigh (1978) asserted that the evidence is overwhelming that overgrazing by livestock is the principal cause of habitat degradation in many riparian areas, not buffalo, deer or other wildlife as some workers had proposed. They also noted that a review of some of the 212 Environmental Impact Statements required of the BLM in relation to 19,000 miles of streams in 17 western states indicated an attitude of "business as usual" in relation to livestock grazing. Reliance was heavy on rotation grazing systems to increase animal unit months of grazing and at the same time to improve riparian habitats; however, these systems were not proven in riparian areas and did not allow time for regeneration of trees such as cottonwood as they did for range forage plants. They emphasized that the Fish and Wildlife Service did not recommend fencing livestock out of all streams or removing livestock from all public lands. They recommended an 11-point plan to protect riparian areas and still allow reasonable livestock grazing (Behnke and Raleigh 1978).

The riparian vegetation of Big Bend National Park was open and severely overgrazed in the early years but has recovered dramatically since the park was established in 1944 and grazing was prohibited. Recently, trespass cattle from Mexico are causing damage and could threaten the ecology in the future. At Amistad Recreation Area, overgrazing has been prevalent for 100

years and the area has been protected only since it was established in 1968. However, some damage still occurs because fences are commonly destroyed and livestock wander in (Schmidly and Ditton 1978). The rodent fauna was very different on grazed and ungrazed sites, jackrabbits were more numerous on the grazed sites and cottontails more numerous on the ungrazed sites. Rinne (1985) in Arizona found that viable research on the impacts of grazing was very difficult because of multiple use concepts, spatial and temporal factors, inadequate controls and replications, and changes in management objectives.

2. Clearing for Agriculture.--The effects of clearing riparian areas for agriculture (cropland) is self evident: cleared land cannot produce the woody plant cover required by wildlife, but the fields do provide food for wildlife (Schrader 1977).

In Arizona, clearing began on a large scale with the arrival of settlers in the 1870's. By 1887, 50,000 acres were in cultivation<sup>e</sup> in the Salt River Valley, 27,000 of this in small grain. Cattle raising also increased greatly, with heavy overstocking in the 1880's that culminated with the disastrous drought of 1892-93 that left the ranges bare of vegetation and 50-90% of the cattle dead of starvation. The construction of dams and irrigation systems allowed more land to be placed in cultivation. Many of the economic realities of past decades still pose a threat to much of the remaining riparian habitat. Clearing for agriculture continues, especially on Indian lands along the Colorado River below Davis Dam. In 1961, these reservations had 80,000 acres of prime arable land covered with phreatophytes. Much of that has been cleared for irrigated farming. Much additional land on the Gila River Indian Reservation also probably will be cleared and irrigated (Fox 1977).

In the Lower Rio Grande Valley of Texas, 95% of the original riparian vegetation has been cleared for agricultural and municipal use since the 1920's. In spite of strong awareness of the value of native brush for whitewing <sup>done</sup> habitat (as well as for other wildlife, game and song birds) the clearing continues at the rate of ca. 2% of the remaining area per year for economic reasons. All land in this area is privately owned except that already purchased for public or private sanctuaries and little can be done to prevent the owners from developing it for agriculture or housing. This situation, the impacts on wildlife, and the management alternatives were thoroughly reviewed by Jahrsdoerfer and Leslie (1988).

Many bird species do not use agricultural areas at all and converting riparian areas to agriculture causes severe losses to insectivorous species. Other birds benefit from the riparian agricultural border effect and other birds (fringillids, doves, cowbirds and some flycatchers) highly use agricultural areas (Conine et al. 1978). In Mexico, a rapidly increasing human population dependent on subsistence agriculture seriously threatens many riparian ecosystems (Deloya 1985).

3. Cutting for Firewood, Charcoal, Construction, etc.--The historical use of cottonwood for firewood <sup>to power</sup> ~~for~~ riverboats on the Lower Colorado was researched by Ohmart et al. (1977). A steamship line operated out of Yuma after a survey made in 1857. The principal fuel was cottonwood, which was plentiful along the river. Fueling stations were established each 25 miles, where the Indians cut and sold the wood. By 1890, river traffic had declined after construction of railroads. All the cottonwoods had been cut that were suitable for fuel such that the few remaining steamboats had to go into the delta for fuel.

The historical record of vegetation along the Gila River was reviewed by Turner (1974), Burkham (1972) and Minckley and Clark (1984). Large areas of mesquite were mentioned which was used to produce charcoal for the mines. Riparian areas near the larger cities were cut for firewood and much of the trees on the Indian reservations was cut for this purpose. The large mesquite bosques used by nesting colonies of whitewinged doves were destroyed by a combination of lowered water tables and wood cutting.

4. Dams for Flood Control and Irrigation.--Along the Lower Colorado, river management practices (mainly the construction of dams) have halted the natural flooding that produces the cyclic regeneration of native vegetation (Turner 1974). Old stands (mostly willow) slowly die and are replaced by saltcedar and screwbean. Channelization has isolated backwater areas from the main channel and increased xeric succession. Lining the channel with boulders has reduced the area for establishment of native trees (Hunter 1984). Until recently, the channelized part of the river never flooded. However, the very large 1983 flood killed most cottonwoods that were inundated and some regeneration will probably occur. Cottonwoods and mesquites are intolerant of long-term flooding, willows are more tolerant and saltcedar even more tolerant (Hunter 1984).

Some of the large floods of the past on the Lower Colorado have destroyed much vegetation in the channel, especially the floods of 1852, 1905, 1907, and 1922. However, this merely continued the cycle of perpetual succession discussed previously. By far the greater modification has resulted from construction of dams--Laguna in 1909, Hoover in 1935, Parker and Imperial in 1938, and Davis in 1943 (Turner 1974). Flooding (annual maximum stage) has decreased greatly since the dams were built and the

occurrence has changed from spring (May-June) to a longer period from April through October (Turner 1974).

Several workers have proposed that saltcedar establishment is favored by the reduction or elimination of flooding after reservoirs are built (Irvine and West 1979, Petranka and Holland 1980, Everitt 1980). Irvine and West (1979) observed that on the unregulated lower Escalante River in Utah saltcedar became established only where large boulders protected them from the water and on steep medium or high flood terraces.

Cottonwood is vernal<sup>ly</sup> adapted; it blooms only in the spring so its seeds can become established only on freshly scoured out areas after spring floods in the natural cycle (Brown et al. 1977b). Saltcedar blooms over a much longer period, from spring and into the early fall, and its seeds can become established after the present summer flood recedes, when cottonwood seeds are no longer present. Similar situations have been created throughout the Southwest wherever dams were built.

Everitt (1980) proposed that the time of peak discharge in the spring on unregulated rivers favored cottonwood but the change to peak discharge in summer below dams favored saltcedar. Campbell and Dick-Peddie (1964) also observed that areas that flooded during the growing season had more saltcedar than areas that flooded in the spring and then had less water in the summer. Petranka and Holland (1980) noted that boxelder, maple, pecan, green ash, and American elm seemed to decrease with reduced flooding, while saltcedar increased.

The accumulation of salt on the soil surface, caused by the fall of the deciduous, salt-excreting leaves of saltcedar, greatly inhibits germination of other plant species. The accumulation of salts in the soil on regulated rivers also inhibits other plants and favors saltcedar; the floods on

unregulated rivers help to flush out the salts (Ohmart et al. 1977). Carman and Brotherson (1982) found that at Lake Utah, saltcedar occurred on soils of higher salinity (700-15000 ppm) while Russian olive occurred on soil of lower salinity (100-3500 ppm).

5. Urbanization, Housing Developments and Recreation, etc.--At higher elevations, most of the land is too rough or stony for agriculture but the middle elevations are prime country for residential subdivisions, especially those now privately owned. Private bottom land along the Verde and upper San Pedro Rivers and <sup>along</sup> Oak and Tonto Creeks are now being converted into retirement homes.

At Oak Creek Canyon, Coconino Co., AZ, bird densities in campgrounds decreased when the campgrounds were open but were similar to natural areas when the camps were closed (Aitchison 1977). Schrader (1977) stated that saltcedar-infested areas were of little value for camping, hiking or picnicking, and also limited bird watching because the trees were too dense and too low and spreading; thinning the stands would improve their value. Water birds were strongly influenced by heavy human usage; diving ducks, loons and grebes, and gulls were most tolerant, coots and gallinules less tolerant, puddle ducks intolerant, and shorebirds most intolerant (Anderson and Ohmart 1984a).

In Big Bend National Park, visitation was 402,433 <sup>in</sup> 1977; 49% of the backcountry use was in the riparian area, 25% for float trips and 24% for camping along the river (Schmidly and Ditton 1976, Ditton et al. 1977). Schmidly et al. (1976) found a significant correlation between "total subjective human impact ratings" and "annual camping use by site," especially in areas of convenient access. However, the effects on rodent densities were not significant, and they concluded that ecological

conditions were not in jeopardy. At Amistad Recreation Area, rodent densities were higher at an overnight campground than at an unused control site (Schmidly and Ditton 1978). Mechanical injury to trees, damage from woodcutting, trampling and elimination of younger age classes were mostly concentrated around picnic tables and restrooms and were minor in the rest of the campground. White-tailed deer seemed to have increased since construction of Amistad Dam (Ditton and Schmidly 1977).

6. Pumping Groundwater.--Pumping of groundwater for agriculture and municipal use in Arizona has been extensive in recent years (Bergthold 1978). The core of influence from hundreds of wells may be widespread, often reaching the seemingly protected riparian areas. The San Xavier mesquite bosque near Tucson so died. The increase in size of Ft. Huachuca caused a housing boom causing water tables to decline toward the San Pedro River, the results predicted by the Arizona Water Commission which had opposed increasing the size of the military base. Vegetation may also die on land purchased for wildlife preservation if lowering of water tables caused by pumping is not controlled (Fox 1977).

7. Phreatophyte Control and Channelization.--During the late 1960's, one of the most widespread and obvious causes of harm to riparian ecosystems was the direct clearing of these areas by government agencies, although the previous construction of dams, clearing land for agriculture, and on the Lower Colorado River, cutting of trees for steamboat fuel may have had greater impacts. During the 1950's and 1960's, a <sup>great</sup> ~~large~~ effort was put into controlling phreatophyte <sup>to</sup> vegetation along streams in Arizona and New Mexico (Carothers 1977) (see section VIII, this report). These projects had two primary objectives: 1) to salvage water for downstream agricultural, municipal and industrial use and 2) to prevent flooding of cities and

agriculture areas. The programs began only after the floodplains were invaded by saltcedar and were aimed primarily at controlling that plant. However, other native riparian plants, such as seepwillow baccharis, willows, mesquite, and even cottonwood, were often included in the list of undesirable plants. The clearing of cottonwoods in the Verde Valley, AZ, some years before 1977 was done for flood control (Fox 1977).

In the early years of the programs, all trees and shrubs in a treatment area, for example in areas of the Gila River, the middle-Rio Grande River, and the middle-Pecos River, were "eradicated" by bulldozing, rootplowing, burning, herbicide treatment, mowing, or by various combinations of these methods. None of the methods lasted very long before regrowth of saltcedar began (the native plants were killed much more easily) and frequent, repeated treatments were required to maintain control, which often involved annual mowing (Bur. Reclam. 1966; PSIAC 1966a,b; Horton 1976, Culler et al. 1982; Weeks et al. 1987).

As concepts changed over time from strictly consumptive use more toward ~~multi-use values~~ <sup>multiple use</sup> and as opposition was encountered from groups oriented toward environmental protection, clearing was usually done along a 1000 ft wide strip with the river in the center and leaving the remaining vegetation.

In the early 1970's, two situations arose that brought clearing operations to a standstill. The first was the failure, despite enormous research effort over several years, to demonstrate any salvage of water that could be used downstream. The second was a series of lawsuits that halted clearing until environmental impact statements were made. Operations since then have largely concentrated on maintenance of previously cleared areas, even though the environmental impact statement may have been approved for clearing. In 1969, nearly two dozen major clearing projects were listed by

the Pacific Southwest Inter-Agency Committee, the largest a-42,000 acre project along the Lower Colorado. Environmental concerns stalled the project, as they did most of the others. However, clearing could still be done because 65% or 155,000 acres of phreatophytes in this area was on private, state or Indian lands (Fox 1977). In the early 1970's, every mile of riparian habitat in Arizona was in the process of being cleared for water salvage and/or flood control or was scheduled for future clearing. The Corps of Engineers' proposed clearing project on the Gila River near Phoenix was blocked by environmentalists together with hunters to save white-winged dove nesting areas. However, the hunters were then denied access to private lands for hunting by the private owners who had wanted their land cleared and favored the project (Fox 1977). In 1970, the Sierra Club and other environmentalist organizations obtained an injunction to stop a phreatophyte clearing project on the upper Gila and San Carlos Rivers until an Environmental Impact Statement was submitted (Gilluly 1971, Hildebrandt and Ohmart 1982). These issues are discussed in more detail elsewhere in this report.

In contrast to the lack of agreement on the value of clearing saltcedar for water salvage, most workers seem to agree that dense saltcedar thickets contribute greatly to increased sediment deposit, narrowing of stream channels and increased flooding. Careful measurement of flood flows before clearing and after clearing phreatophytes indicates that the height of flood waters are in fact reduced after vegetation is cleared.

8. Fire.--Many rangeland ecologists believe that the periodic burning of southwestern rangelands throughout history (and prehistory) was a major benefit to sustaining the grasslands of this area; also, that the reduction of the use of fire was a major factor allowing the enormous increase in woody vegetation that has invaded and displaced much of these grasslands

during the last 100 years (Wright and Bailey 1982). However, fire generally is destructive to riparian areas. Along the Lower Colorado, 21 of the 25 stands of saltcedar examined had burned within the previous 15 years (Anderson et al. 1977a). After fires, saltcedar and arrowweed quickly regenerate, willows and mesquite occasionally regenerate, and cottonwoods and Atriplex usually die. In favorable sites, saltcedar sprouts can regrow to 10 or 12 ft high in a year after burning (Horton 1977). In mixed stands, saltcedar will quickly gain dominance if the entire stand burns. Value to wildlife other than doves increases for two years after burning then decreases drastically as saltcedar matures (Hunter 1984).

9. Exotic Plant Invasions.--The invasion of two exotic plants, saltcedar and Russian olive, has had disastrous consequences in riparian areas of the western United States, especially in the Southwest. Of the two, saltcedar is much more widespread but Russian olive is spreading; both can become problems in more northern areas in the future. The impact of saltcedar on water usage, displacement of native vegetation and the consequent impacts of this on bird and other vertebrate populations and the harmful effects of the measures used to control it, are discussed at length elsewhere in this report.

#### C. Effects of Habitat Degradation on Wildlife

Programs of phreatophyte control, channelization and other river management procedures caused great alarm among groups who were concerned about the effects of habitat modification on wildlife. As a result, a number of large-scale studies of the importance of riparian areas to wildlife were conducted, which were funded by the agencies previously engaged in the clearing operations (see section "Riparian Habitat and Non-Game Birds"). These studies have enormously enlarged our knowledge of

the potential values of saltcedar and other habitat for birds and other wildlife.

The consensus opinion of most biologists who have studied the white-winged dove in recent years is that loss of nesting habitat is the greatest threat to the continued existence of the large colonies needed to produce the high densities of doves in feeding areas favored by hunters (Cottam et al. 1968, Brown et al. 1977a, Wigal 1973, Cunningham 1986, George 1985, 1988b, Fish and Wildlife Service 1980). The continued existence of whitewings as an abundant species seems to be in no danger.

In the Lower Rio Grande Valley of Texas, whitewings originally nested in many thousands of acres of dense forests and thickets of Texas ebony, huisache, and other trees. Whitewing populations probably increased as agricultural land was developed (especially for small grains) because of the increased food supply for the doves; water was always available from the river. They nested in dense colonies in this vegetation. However, since 1920, more than 99% of the original nesting habitat has been cleared. Whitewings have increasingly nested in citrus but this habitat is unreliable because of periodic freezes, which several times have caused drastic decreases in whitewing populations; also, citrus does not support the dense nesting colonies found in native vegetation. By 1968, less than 1000 acres of prime native habitat remained (Cottam et al. 1983).

In Tamaulipas, where 19 million whitewings breed, a similar trend is now developing. Clearing the brush for agriculture has possibly increased whitewing populations in recent years by increasing small grain food supplies. However, continued clearing will eventually decrease nesting sites until the whitewing population falls, maybe drastically (Ron George,

TP&WD, Jan. 1989, pers. comm.). This could be very serious to hunting since perhaps 80% of all whitewings in North America nest in this area.

By 1920, the bottomland near Arlington, AZ, was composed of patches of mesquite with willows and cottonwoods bordering the river, which still flowed. The mesquite patches were already broken up by farms, but the largest bosque, over a mile square, contained ca. 2000 adult pairs of whitewings. Dove numbers had been reduced near Phoenix and Tucson (Wetmore 1920).

By 1940, the largest whitewing populations in Arizona were in the river-bottom "jungles," especially the New York thicket above the Salt-Gila confluence. By the late 1930's, populations seriously declined, probably due to overhunting. A shortening of the season to 15 days allowed whitewings to increase by 1950 (Lawson 1950) and the season was lengthened to 3 months and the bag limit raised from 10 to 25 per day. Shaw (1961) described conditions along Gila River from Gillespie Dam to the Salt River as ideal for doves. In this area of 20,500 acres, 7000 acres were in saltcedar, 2500 acres of it mature enough for extensive nesting. Shaw and Jett (1959) estimated 400,000 nesting doves in this area, which with their progeny and the unmated doves, might exceed 1,000,000; of these, 66% were whitewings.

In many areas, the saltcedar is too short to be much used by whitewings. Along the 275 miles of the Lower Colorado from the Nevada to the Mexican border, Younker and Anderson (1986) reported 107,649 acres of riparian vegetation, probably 57% of it saltcedar; however, only 234 acres (including saltcedar) was in Structural Type II that is preferred by whitewings (Table 2, Table 28). Whitewings do nest in the lower structural types to a considerable extent but at much lower densities than in the preferred Type II. Along a 58 mile stretch of the Gila River east of Yuma,

over 50% of the vegetation was saltcedar but trees over 8 m tall were uncommon (Haase 1972).

The reason for the lack of taller trees is probably the frequent fires and frequent mowing or other saltcedar controls used to maintain the floodways. Anderson et al. (1977a) reported that 21 of the 25 stands of saltcedar studied along the Lower Colorado had burned within the previous 15 years. With this frequency of burning, the few stands of saltcedar that reach sufficient maturity to be attractive nesting habitat for whitewings are likely to survive only a few years before they burn again. A similar situation exists at the Bosque del Apache <sup>National Wildlife Refuge</sup> on the Middle Rio Grande (John Taylor, pers. comm.).

#### D. Prevention of Habitat Degradation and Reclamation of Degraded Areas

1. Land Acquisition for Wildlife Habitat.--Only two effective options seem feasible to prevent further habitat degradation in many southwestern areas: 1) purchase of land from private owners which then will be managed for wildlife habitat, and 2) prevent <sup>loss of</sup> further flooding of habitat by the construction of new dams.

A limited amount of land has been purchased in the Lower Rio Grande Valley for wildlife habitat. The <sup>U.S.</sup> Fish and Wildlife Service began the process by the purchase of the 2500-acre Santa Ana National Wildlife Refuge in 1943. Today, over 2,280,000 acres have been acquired in Texas (Table 5), nearly half of it in Big Bend National Park. However, only 7,436 acres are in riparian areas of the Lower Rio Grande Valley (Table 5).

Table 5. Land acquired for wildlife habitat in Texas (Fish and Wildlife Service 1980).

	Texas		Lower Rio Grande Valley	
	<u>No. sites</u>	<u>Acres</u>	<u>No. sites</u>	<u>Acres</u>
Fish and Wildlife Service	11	164,000	4	3,721
National Park Service	6	1,172,013		
Forest Service-USDA	6	697,435		
Texas Parks & Wildlife Dept.	17	216,587	14	3,500
World Wildlife Fund	several	4,400	1	1,400
National Audobon Society	10	18,515	1	170
Welder Wildlife Foundation	1	<u>7,800</u>		
		2,280,750		7,436

An additional 19 sites totaling 990,400 acres were being considered for acquisition in the Unique Wildlife Ecosystems Program, 3 of these sites also in the Lower Rio Grande Valley (Fish and Wildlife Service 1979) and to date ca. 25,000 acres have been purchased (Ronnie George, TPWD, pers. comm., January 1989). In addition, a corridor along the entire Lower Rio Grande has been proposed that would connect all the scattered riparian sites (Fish and Wildlife Service 1979, Jahrsdoerfer and Leslie 1988). Most of these proposals still await funding. In 1985, TPWD purchased ca. 2,000 acres (including 400 acres of bottomland) near Ruidosa in the Trans-Pecos area for white-winged dove habitat (Ronnie George, pers. comm.).

The Texas Parks and Wildlife Department is revegetating their acquired land with native trees: Texas ebony, huisache, anacua, granjeno, and brasil, but Texas ebony and huisache are best. Water development projects have been proposed for additional municipal and agricultural use that would flood nearly the entire remaining native riparian area of the Lower Rio Grande

Valley. All new reservoirs have been opposed by the Fish and Wildlife Service because of habitat destruction (Ramírez 1986).

In Arizona, 87% of the area of the state is in public lands, but in some areas much of the most valuable area (riparian areas which constitute less than 0.75% of the state area) is privately owned (Bergthold 1978). Acquisition of private lands would offer a solution to such areas as the San Pedro River, AZ (McNatt 1978). This area has been recently designated a National Conservation Area. On public lands, changes in policy in administering these lands could provide adequate protection, but probably would be strongly opposed by many of the present lessees who use the areas for livestock grazing or agriculture. Some areas would require the acquisition of water rights if effective habitat were to be maintained (Brown et al. 1977a).

In 1978, the Fish and Wildlife Service had acquired 35 million acres in the National Wildlife Refuges in the United States. In 1985, that amount was 90 million acres, with most of the new areas in Alaska. However, in the 48 lower states, much of the newly targeted land is in riparian areas. In Texas and Oklahoma, several hardwood bottom areas are being considered. The recently acquired San Pedro River area in Arizona is one of the last large "uncontrolled" rivers in the Southwest (Spear 1985).

2. Revegetation of Saltcedar-cleared Riparian Areas.--Previous programs to clear saltcedar from riparian areas of southwestern rivers, using either chemical or mechanical controls, have left these areas mostly barren of vegetation or with grass or with saltcedar in various stages of regrowth which require repeated retreatments. The native cottonwood-willow, honey mesquite, screwbean mesquite and other shrubs usually have not returned and the value of these areas for wildlife habitat remains low. Numerous attempts have been made, particularly along the Rio Grande and Pecos Rivers in New

Mexico and the Lower Colorado River between Arizona and California, to revegetate these areas with various grasses and with the original native trees and shrubs. Several areas also have been revegetated along the Lower Rio Grande of southern Texas to provide wildlife habitat; this work was not related to saltcedar control since saltcedar does not grow there. Biological control of saltcedar is expected to be a gradual process over several years in any given area which, hopefully, would allow the native shrubs and trees to return naturally (if soil salinity and water table depth permits). If this were not to occur at a satisfactory rate, then planned revegetation should be carried out as has been attempted on certain herbicide-treated areas.

On the Lower Colorado River, Anderson and Ohmart (1984a) reported that they were able to replace saltcedar with fewer trees of cottonwood, willow and mesquite, reduce water usage, obtain less vegetation at the lower levels which would more easily allow passage of flood waters and reduce flooding, and at the same time improve wildlife habitat.

a. Examples of revegetation projects.--On the Gila River at Sar Carlos, AZ, tests in field plots cleared of saltcedar in a 10-acre site failed to establish replacement vegetation (Mace et al. 1966). Of six species of grasses (bermudagrass, alkali sacaton, sand dropseed, Lehman: lovegrass, blue panicgrass, and buffelgrass) seeded in September 1964, only a few isolated plants survived by the next summer. They attributed this failure to: 1) not covering the seed, 2) seeds washing away in heavy rains, and 3) possible loss from wind, rodents and insects. The plantings were duplicated on May 1, 1965, using a rangeland drill. However, no seed had emerged by July 31 even though the plots were irrigated, probably because of high soil salinity. Salinity of the soil ranged from 33,770 at 400 ft from the river to 1050 ppm at 800 ft; the irrigation water from the site varied

*Sodgrass (Distichlis) was not included.*

from 11,500 to 20,400 ppm. Laboratory tests showed that germination of these species of grasses was reduced to nearly zero at 6720 and 8725 ppm. Mace et al. (1966) concluded that seed germination could not be expected near the Gila River unless the salt concentration of the surface soil could be reduced.

The revegetation efforts along the Lower Colorado River and in New Mexico were preceded by the preparation of vegetation-type maps for the area (Anderson and Ohmart 1976, 1984; Younker and Anderson 1986) and analyses of wildlife usage of the various vegetation types as discussed in section VII of this report, in which saltcedar was shown to have little value to most species of birds and mammals.

The first attempt to clear saltcedar and revegetate the area with more beneficial native trees and shrubs was begun on the Lower Colorado River floodplain in 1977 by the Bureau of Reclamation and the Fish and Wildlife Service at the Cibola National Wildlife Refuge (Anderson et al. 1978, Anderson and Ohmart 1979, 1982<sup>p</sup>, 1984a). This work and two other projects were reviewed by Kerpez and Smith (1987) and Pinkney (1990). They concluded (based on 2 years of data) that establishment and rapid growth of cottonwood, willow and mesquite was possible if good sites were selected and correct planting and maintenance methods were used. Mills and Tress (1988) concluded that riprapped banks could be revegetated but planting would be easier and just as valuable to wildlife if made adjacent to the banks.

In his detailed review of the 17 previous revegetation projects along the Lower Colorado River planted between 1979 and 1987, Pinkney (1990) listed numbers of each species planted, type of plants (poles, containers, seed, etc.), date of planting, soil preparation, site description, and results obtained (survival, growth, etc.). A total of 37,040 trees were planted

"Final" report  
dated 1992

(all but 60 of them ~~in containers~~) at the 17 sites including 8,183 cottonwoods, 3,603 willows, 19,937 honey mesquites, 366 screwbean mesquites, 1676 palo verdes, 2710 quailbushes and 478 of other species (+87 of unrecorded species) (Table 6).

Results mostly have been less than satisfactory. The causes for poor survival and growth were obvious in some cases and unknown in other cases. Some sites were flooded by the river, several were severely browsed by cattle, deer or rabbits, some sites had water tables that unexpectedly fell, at some sites the holes were not augered deeply enough, some sites had far too high salinity levels, some sites were not irrigated properly, and some sites has severe insect damage. Needed data were not collected at some sites, such as depth to water table, soil salinity or even number or species of trees planted. Most plots are recent plantings and require monitoring for several more years to determine results. Rarely were real experimental plots established that would define the parameters for survival and acceptable growth rates, such as depth to water table, soil salinity, irrigation needs, etc. Pinkney (1990) reviewed the data, and revisited the sites to collect recent data on survival and growth, then attempted to draw some conclusions, based on this series of largely unrelated plantings in variable conditions, to establish guidelines for future projects.

Some of the sites had good survival rates when examined in 1988, but this was only 1-2 years after planting at most sites. Best long-term results were at the Cibola Dredge Site. At the conclusion of the study, cottonwood growth of 6 times the height and 16 times the biomass at planting and willow of 4 times in height and 7 times in biomass were not uncommon; mesquite growth was also good. Survival was still quite high in 1988 (Table 6). More recently, many of the cottonwoods appear stressed and senescent and mortality of the

Table 6. Plantings, results and costs of 17 revegetation projects along the Lower Colorado River (from Pinkney 1990).

Location	Date planted	Size & cost		Number trees planted							% Surviving in 1988						
		A	\$/A	CO	W	HM	SM	PV	Q	Other	CO	W	HM	SM	PV	Q	Ot
Real Slough	80-87	15	1,454	212	133	± 150		40			7	16	±60		15		
Oplock	86	5	2,334 <sup>c/</sup>	400	50	150					45	62	59				
iprap A-3 (poles)	86			151	152						64	50					
iprap A-5 (poles)	87			30	30						66	40					
o name lake	87	41	4,264	1,380	370	3,560	--	395	100	330	?	?	?	?	?	?	?
11 Backwater <sup>a/</sup>	84-87		2,000 <sup>c/</sup>	345	75						0.28	0					
xbow North	84	1	2,100														
xbow South	86	6	2,874	175	175	300			4		91	86	79				?
xbow BLM <sup>b/</sup>	83	4		160	40	12					6	0	0				
xbow seeding	86																
ibola seeding	86																
ibola NFW	79-80	50	3,794	607	765	304		265			2	4	56		0		
ibola Dredge	79	75	3,679	607	607	304		265			103	49	66		56		
ittry Lake	86	57	8,323 <sup>d/</sup>	3,376	408	733	366	711	2,610	144	?	?	?	?	?	?	?
ortuna, Yuma	85	44 <sup>e/</sup>	7,500 <sup>d/</sup>	200	100	?					128	87	?				
acna A	86	108-138	10,464 <sup>d/</sup>	540	540	11,124					32	6	20	85			
acna B	86	30	?			3,300											
TOTAL				8,183	3,603	19,937	366	1,676	2,710	478							

/ High soil salinity plus severe damage by deer and cattle.

/ Flooded by river in 1983; many willow, screwbean mesquite and much arrowweed established naturally after the flood.

/ Labor and some other costs not included.

/ Costs appear too high but might be realistic on some sites.

willows has increased dramatically. Although mortality rates of palo verde, mesquite and quailbush approaches 40%, the remaining plants appear healthy and vigorous (Pinkney 1990). An additional evaluation of all sites was made in 1990 (Pinkney 1990) but was not yet summarized at the time the present report was prepared. Survival at 10 research sites varied from 24 to 86% through 1989. Survivorship on the dredge soil site was 65% in 1989, with most surviving cottonwoods and willows in poor condition. Tree survivorship at the refuge site was about 12%, but quailbush (Atriplex lentiformis) which was seeded there was still doing well. Causes of recent mortality at both sites are largely unknown. Weed, insect and vertebrate pests were responsible for part of the mortality and slow growth, but many trees failed to survive in the apparent absence of pests (Rorabaugh, pers. comm., April 1990).

Swenson and Mullins (1985) developed a less expensive method for revegetating riparian areas. They drilled holes to the water table 7-12 ft below and inserted cut dormant saplings in the holes during the winter. They obtained 60-100% survival of Fremont cottonwood, narrowleaf cottonwood, and Gooding willow with no irrigation on the Rio Grande floodplain near Albuquerque, NM. However, they found that more than 3 months' flooding killed the plants and that beavers and cattle would kill them. Plantings along the Pecos River all failed, probably because the salt content (4,000 ppm) was too high.

An extensive revegetation program has recently begun on the Bosque del Apache National Wildlife Refuge, on the Rio Grande River near Socorro, NM (John Taylor, pers. comm. March 1989; Kerpez and Smith 1987). In this program, the saltcedar is sprayed for 1 or 2 years with "Arsenal," a broad-spectrum herbicide that kills nearly all types of vegetation present. The dead plants are then bulldozed into piles and burned.

In an alternative method, the herbicide is applied with a tractor-mounted "wiper-roller" (Mayeux and Crane 1983) if the plants are small enough. This latter method applies herbicide only to the saltcedar above a set height and does not kill other vegetation below this level. Recently, herbicidal controls have been discontinued and the saltcedar is removed and the site prepared for planting by cutting and burning, root plowing and raking. The area is then planted with 40 poles of cottonwood/acre, inserted to the water table (ca. 8-10 ft deep) in the augered holes. Small dikes are built around the revegetated area (not difficult because the soil surface is almost level here) and flooded for a short time to kill new saltcedar seedlings soon after they germinate. The poles are provided by the Los Lunas Plant Materials Center near Albuquerque; 60% are native cottonwood, 30% Fraiser hybrids and 10% other hybrid cottonwoods that are salt tolerant. Black willow and screwbean mesquite are also planted and an understory of wolfberry, New Mexico olive, four-winged saltbush, and skunkbush is planted, using bare-root seedlings. Soil salinity is tested and only the more salt-tolerante species are planted on the areas (ca. 30% of the total) with salinity above EC-3. Plans are to revegetate 150 acres/yr by these methods and the first 5 plots have been completed. Survival of the pole plantings of cottonwood and willow is 85-90% and that of the shrubs is 50-60% (John Taylor, pers. commu., December 1990).

R ? Freshed

By using the best methods now developed, survival of trees exceeds 95% and contractors have guaranteed (and obtained) such survival in revegetation projects on the Rio Grande of western Texas (Robert Ohmart, pers. commu., March 1989). Webb and Dodd (1981) have developed methods of revegetating sandy material dredged from Galveston Bay, TX, using saltcedar (I. gallica).

↑  
canonensis

sand pine, gulf croton, live oak, dwarf sumac, and southern wax myrtle (Baccharis halimifolia).

b. Effects on wildlife enhancement.--Anderson and Ohmart (1984a), developed a predictive model to estimate wildlife enhancement produced by revegetation. Enhancement increased with the percent of cleared area revegetated, from zero at 10% revegetated, to 42% enhancement at 20%, 301% enhancement at 50%, and 733% enhancement at 100% revegetated, compared with Type IV saltcedar. Optimum enhancement was obtained with a ratio of 50-60% cottonwood-willow to 40-30% honey mesquite, although any ratio gave great enhancement. In their field plots, about 44% of the 30-ha dredge-spoil site was revegetated. They measured a wildlife enhancement of 7:3 or 2.33 compared to saltcedar IV, or 76% of the 3.08 value predicted by their equation. If shrubs that regrew had been included with the cottonwood, willow and honey mesquite that they planted, the enhancement would have been 5 times that of SC-IV (Anderson and Ohmart 1984a). Wildlife usage of the cleared areas increased rapidly. After trees were planted during the winter, bird density in the plots increased from near zero in April to 3-4 times that of the uncleared saltcedar during the fall and winter. The number of bird species increased uniformly from only 3 or 4 in April to equal or slightly more than the saltcedar in February (Anderson et al. 1978). Anderson and Ohmart (1985) found that clearing strips of saltcedar also had a negative effect on wildlife that was more negative as more was cleared. They recommended that revegetation plots should be at least 20 ha in size and that the replacement species should be planted in plots of 1-2 ha for each species rather than intermixing the species. Also, poor results could be expected if soil salinity were too high; the soil should be tilled and weeds controlled (Anderson and Ohmart 1984a).

c. Factors influencing success.

1. Species of plants used.--Pinkney (1990) listed the species of trees, shrubs and grasses that have been used, or have potential for use, in various riparian revegetation projects in the southwest. Sixteen species (7 herbaceous and 9 woody, including the exotic saltcedar, athel, false bamboo or giant reed [Arundo donax]) were used by the U.S. Soil Conservation Service in California (Schultze and Wilcox 1985, Gray et al. 1984), 33 species (9 trees, 10 shrubs and 14 grasses, including the exotic Russian olive, bermudagrass, giant reed and love grass) are being used in projects mostly in New Mexico (Swenson 1988, 1990b), 7 tree species are under investigation for propagation and use (Oaks et al. 1989), 10 tree and 5 shrub species (including Russian olive) are recommended for revegetation along the Rio Grande below 4800 ft elevation (Pinkney 1990), 5 tree species are available for commercial production (including Russian olive) and 7 others need additional development (Swenson 1988). Pinkney (1990) listed 23 species of grasses, 4 forbs, and 25 species of shrubs available for testing in the New Mexico long-range program.

The revegetation of areas cleared of saltcedar by more "desirable" plants would appear to have potential both for reducing usage of groundwater and rainfall and for providing more suitable plants for wildlife food and shelter or for livestock grazing. McGinnies and Arnold (1939) determined water use by 28 species of range plants growing in lysimeter tanks at the Santa Rita Experimental Range near Tucson, AZ, from 1932-1936. During the summer, perennial grasses and summer annuals had the highest water use efficiencies (generally 400-500 g water:1 g dry matter produced). During the cool season, winter annuals and perennial grasses were similar in efficiency (generally 500-800:1). Trees and shrubs (including velvet mesquite [Prosopis velutina],

catclaw [Acacia greggii], and burroweed [Haplopappus fruticosus]) were very inefficient users of water (generally 1700-2400:1) through paloverde (Cercidium microphyllum) was an exception with an efficiency of 772:1. They noted that most workers agreed that water use efficiency was greatest under optimal growing conditions for each species. However, only the water requirement for a given species gave no indication of the adaptability of that species to the environment. An example was that both velvet mesquite (1723:1) and Rothrock grama (418:1) grew successfully side by side near the experimental area (McGinnies and Arnold 1939).

Substantial effort and progress has been made during the past 10 years to select superior ecotypes of native trees for revegetation, rated on rooting vigor, growth rate, crown spread, leaf density, salinity tolerance and competitive abilities. Several superior hybrids of cottonwood and poplar also have been developed and tested. This research was first done at the USDA-Soil Conservation Service's Plant Materials Center at Los Lunas, NM, and later also at the SCS's Tucson Plant Materials Center and at the USDI-Fish and Wildlife Service's Bill Williams National Wildlife Refuge in Arizona (Pinkney 1990).

Most of the species used in riparian revegetation projects of the southwest are native to the area and are components of the historic riparian community. However, some exotic species have also been used, some of which are or have the potential to become serious weeds, such as saltcedar, athel, Russian olive, lovegrass, bermudagrass, and giant reedgrass (Arundo donax). The ecological implications of establishing these exotic species and their potential to become weedy should be thoroughly investigated before using them even experimentally. The history of agriculture and of native plant communities is already replete with cases of serious weeds that were introduced by well-

meaning private individuals or agriculturalists with a view only of a narrow beneficial usage but who were unaware of the broader consequences of their spread into native plant communities or other areas of the agroecosystem.

This situation is particularly dangerous in riparian revegetation projects where the objective is to discover and use plants sufficiently aggressive (and, therefore, potentially weedy) to not only sustain themselves but possibly also to outcompete the presently weedy saltcedar. A case in point is the observation (Pinkney 1990) <sup>by Anderson and Clement (1982)</sup> that bermudagrass almost completely inhibited the establishment of seedling saltcedar. <sup>They</sup> He did not mention whether or not bermudagrass also inhibited the establishment of seedling cottonwood, willow, mesquite or other native plants. Also, lovegrass, that is being used in some riparian projects in New Mexico, has essentially excluded most of the native grasses on large areas of the Santa Rita Experimental Range south of Tucson, AZ. Russian olive that also has been used in New Mexico and is available for commercial production is regarded as a serious exotic weed of riparian areas by some ecologists (Kopft, pers. comm.). Part of the present saltcedar problem is reputed to have resulted from deliberate plantings of saltcedar for streambank stabilization. The use of such plants may simply replace saltcedar with another weed nearly as harmful.

2. Depth to groundwater.--Depth to the water table is one of the most important factors affecting the survival and growth of plantings used for revegetation. Dormant cottonwood poles have been planted at many sites along the Rio Grande in New Mexico at water table depths of from 1 to 13 ft (Bur. Reclam. 1986, Shrader 1989), on the Gila River near Safford, AZ (York 1985, 1986), and on the Lower Colorado River (Anderson 1988a,b,c). Pinkney (1990) concluded from these studies that the best survival was at water table depths of 1.5 to 5.0 ft, with fair survival in some areas at

depths to 10 ft, but plantings should not be made at depths greater than 15 ft. Rooted honey mesquite, screwbean mesquite, and palo verde plants in containers could establish over water tables to 12 ft deep. Shallow water tables (less than 1.0-1.5 ft) were detrimental to most species, with willow having the highest survival.

3. Soil salinity.--Pinkney (1990) concluded that soil salinity begins to affect growth of cottonwood and willow at levels greater than 1200 ppm (ca. 2.0 EC) and plantings should not be made if salinity exceeds 2000 ppm (ca. 3.0 EC) (1EC=ca. 640 ppm). Plantings on the Rio Grande at salinities of 625-775 mmhos/cm did not affect growth (Bur. Reclam. 1986). At Bernardo, NM, pole plantings of cottonwood, willow and poplar were seriously affected at 2700-3000 ppm (Fenchel et al. 1989) and plantings along the Pecos River, NM, mostly failed with groundwater salinity that sometimes exceeded 6,000 ppm (Swenson and Mullens 1985, SCS 1989). On the Kern River Preserve, CA, biomass of cottonwood was reduced by 40-50% for cottonwood and 58% for willow after 2 years when EC exceeded 3.0 (Anderson 1986). The effect was even greater after 3 years (Anderson 1988b).

Kerpez and Smith (1987, citing pers. commu. with B. W. Anderson and R. D. Ohmart) suggested that plant species with different salinity tolerances could be used in soils of different salinity levels, as follows:

<u>Groundwater Salinity (ppm)</u>	<u>Plant</u>
2000 or less	Black willow, Fremont cottonwood, honey mesquite, blue paloverde, quailbush, inkweed
2000-4000	Fremont cottonwood, honey mesquite, blue paloverde, quailbush, inkweed
4000-10,000	Honey mesquite, blue paloverde, quailbush, inkweed
10,000 or more	Quailbush, inkweed

~~HP~~. Anderson now suggests that the above salinity tolerances should not be so precisely defined, although they are, in general, valid (J.<sup>C.</sup> Rorabaugh, U.S. Bur. Reclam., Yuma, AZ, pers. comm., 1989). <sup>1</sup>

4. Soil type.--The most suitable soils for revegetation are sandy to clay loams without subsurface clay lenses, or with only a few, thin lenses (Pinkney 1990). On the Rio Grande in New Mexico, 82% of pole plantings survived on the Percha Field Farm, which was the best of the 13 sites (Bur. Reclam. 1986). Deep tillage, by augering holes to the water table, is essential to good survival of revegetation plantings; a 12-in. auger is the minimum size acceptable and a 20-in. auger is preferable (Pinkney 1990). Tillage breaks through any dense clay lenses or that are common in alluvial soils and allows the plant roots to penetrate to the water table. If not broken, these subsurface areas of dense soil block root penetration and cause them to spread laterally. At the Kern River Preserve in California, pole plantings with deep tillage all survived and produced 7 times the biomass as those with no tillage, which has 43% mortality after 3 years (Anderson and Ohmart 1982b, 1984a); survival increased as depth of tillage increased (Anderson 1987).

5. Irrigation.--Various systems, daily amounts and duration of irrigation have demonstrated that at least initial irrigation is important to survival of container plantings on the Lower Colorado (Pinkney 1990). A 150-day irrigation season using 32 gal/day per tree produced good survival of cottonwood and willow but was too much for honey mesquite and palo verde (Anderson and Ohmart 1982b). On the Kern River Preserve, a 30-day initial period was as good as a 90-day period; where the water table was deeper than 4 ft, more than 8 gal/day was needed (Anderson 1986, 1987).

Various methods of water harvesting, conservation and water-absorbing polymers are under investigation. The polymer "HydroSource" may be useful on sandy soils, small catchments help to collect rainfall, and black polyolifin film prevents evaporation and prevents weed growth (Pinkney 1990).

6. Damage from weeds, insects, wildlife and livestock.--Control of competing weeds, damage from insects, and browsing by deer, cattle, small rodents, rabbits and removal by beavers is a key element to successful establishment of replacement vegetation. Weeds reduced survival of plantings in several location by 10-15% and preemergent herbicides were needed for control. Woven-wire structures around each pole provided protection from mammal feeding and a systemic bitterant, sold under the brand name "ANI-PEL" appears effective as a feeding repellent in early testing. Competition by bermuda grass caused losses at some sites (Pinkney 1990).

7. Summary - Criteria for success.--In developing a revegetation project, Pinkney (1990) emphasized the importance of defining goals (restore cottonwood-willow gallery forests, increase plant and animal species diversity, provide habitat for endangered species, etc.) and setting criteria for measuring success; he stressed that monitoring should extend over several years. After reviewing many revegetation projects, he concluded that great care should go into selecting revegetation sites. He listed 6 steps that should be considered in site selection:

- 1) Describe the events that led to the present condition (changes in surface flow, ground-water tables, mechanical disturbance, invasion of exotic plants, overgrazing).
- 2) Describe primary and secondary land uses of the site (near agricultural or urban areas, proposed for development, recreational usage).
- 3) Limitations to establishment and growth of vegetation and wildlife habitat (precipitation; temperature; flooding; water table depth and fluctuation; weeds; soil texture, moisture and salinity; potential animal and insect damage).

- 4) Evaluate physical ~~site~~ features (accessibility for equipment, irrigation water and power availability).
- 5) Describe the ecosystem and wildlife habitat desired (wildlife species desired, special-interest species present, can non-native plants be used, degree of wildlife diversity desired, intensity of future management).
- 6) Describe monitoring plan (methods, data desired, frequency and duration).

Anderson and Ohmart (1982b) concluded that, on the Lower Colorado River, the most important factors increasing survival were 1) deep tillage, in which a hole 8 in. dia is augered 10 ft deep or to the water table; 2) prevention of competition from other plants, especially from bermuda grass; 3) irrigation for at least 150 consecutive days; and 4) planting only in areas where the water table is less than 15 ft deep and the salt content less than 1200 ppm. In their review of revegetation efforts, Carothers et al. (1988) concluded that the greatest key to success was matching the requirements of the plant species used with the site conditions.

Results of 13 plantings of dormant poles of cottonwood, willow and hybrid poplar along the Rio Grande, NM, indicate that for successful establishment, poles should be 1) completely dormant when cut; 2) cut from rapidly growing trees having basal diameters of 2-4 in. and most buds removed; 3) planted in augered holes within a few days of collection; and 4) should not dry out before planting (Pinkney 1990). Research at the SCS Plant Materials Center at Los Lunas, NM, has developed superior ecotypes of cottonwood and willow and methods of producing planting stock (Fenchel and Swenson 1989).

Rooted cuttings of cottonwood and willow grown in containers were used on the Lower Colorado projects (Anderson and Ohmart 1982, Anderson 1986, 1988b); honey mesquite and palo verde plants were grown from seed. Cuttings should be at least 16-24 in. tall, and those in containers 18 in. deep survived better (Pinkney 1990).

d. Monitoring.--The importance of monitoring of revegetation projects has been recognized (Anderson 1988b, Carothers et al. 1988, Kasprzk and Bryant 1989, Szaro and Rinne 1988) and Pinkney (1990) recently reviewed the past efforts and made recommendations. Monitoring often was the missing element in past projects, mostly because of the difficulties of arranging long-term funding. A definitive evaluation of the success of a program requires a decade or more but could be intensive for the first few years and reduced to once each 5 years thereafter (Pinkney 1990).

e. Costs of revegetation.--Pinkney (1990) reviewed the costs of the 17 revegetation projects on the Lower Colorado River. Costs varied greatly because of site characteristics and because all costs were not included in some projects. Costs per acre varied from \$1,454/acre at the Beal Slough to <sup>13,600</sup> ~~\$10,464~~ <sup>to Tuma Pond</sup> /acre at the ~~Tacna A and B~~ sites. Pinkney (1990) concluded that the most representative and best documented sites were the Cibola National Wildlife Refuge site and the Cibola Dredge Spoil site, which cost \$3,794 and \$3,679 per acre, respectively (Table 6). <sup>(pg 71)</sup> A breakdown of the costs, converted to 1990 dollars in given in Table 7; cost per tree was \$173.78 and \$119.41 at the two sites. Through 1989, Rorabaugh et al. (1989) reported that costs of revegetation with drip irrigation on 10 sites on the Lower Colorado River has ranged from \$24 to \$138 per plant; usually, 100 trees were planted per acre. At these prices, revegetation of the approximate 48,000 acres of saltcedar along the Colorado River, at \$4700/acre, would cost ca. \$226 million.

In addition, Pinkney (1990) estimated that evaluating site suitability would cost \$30-50/acre. Monitoring costs were not well documented but one estimate was 10% of the cost of a project. The above costs were for 1-gal container-grown trees which were very inexpensive (<sup>1.50</sup> ~~\$1=60~~ <sup>1.75</sup> to \$2.50 ea). Poles

for planting cost ~~\$6.00~~ each on the Rio Grande, NM. Pinkney (1990) proposed that careful site selection could reduce costs of site preparation by 50-75% and could eliminate irrigation costs. Given the low cost of the 1-gal container plants, using larger plants should be very cost effective if survival rates could be substantially increased.

Table 7. Costs of revegetation of two representative sites on the Lower Colorado River (from Pinkney 1990).

Item	Refuge site		Dredge site	
	Cost/A	% of total	Cost/A	% of total
Labor (planting, irrigation, daily operation, management)	\$1,731	36.2	\$1,784	38.4
Site preparation (clearing, storage pond, etc.)	798	16.7	185	4.0
Irrigation system, supplies, fuel	150	3.1	654	14.1
Trees	101	2.1	67	1.4
Truck lease, gasoline, misc.	209	4.4	187	4.0
Fringe benefits	398	8.3	410	8.8
Indirect costs	1,390	29.1	1,348	29.1
TOTAL	\$4,777		\$4,634	
COST PER TREE	\$119.41		\$173.78	

Anderson and Ohmart (1979) originally estimated the cost of clearing and revegetation on the Lower Colorado River at \$10,000/ha but later reduced this to \$2,690/acre (excluding 41% indirect costs of the contract). They estimated that careful site selection and irrigation methods could reduce this to ca. \$1,600/acre for cottonwood and willow and that quailbush would cost only \$698/acre.

Costs at the Bosque del Apache <sup>near Las Vegas,</sup> on the Rio Grande, NM, during the first year were approximately that of the <sup>Lower Colorado River</sup> California projects. However, as experience was gained and changes were made, costs have been reduced to

\$600-1500/A. Costs are less than on the Lower Colorado primarily because of less cost for irrigation (John Taylor, pers. comm., Dec. 1990).

Revegetating native brush habitat along the Lower Rio Grande River costs about \$165 per acre (George 1985). The difference in cost between here and the western areas is due to differences in irrigation and other methods and amount of labor needed to obtain satisfactory revegetation rates. These efforts are minimal in Texas where the seeds of native tree species are gathered and grown in a greenhouse for up to six months. The seedlings are then planted with a tree planter pulled by a tractor.

3. Management of Riparian Areas within Public Lands. --The management of public lands in the West has been a highly controversial topic in the political arena for many years, pitting the long-time lessees for livestock grazing against environmentalists and others who want other uses considered. These multi-use objectives have been emphasized by Horton (1976), Shrader (1977), McCormick (1978), and others and in several national symposia (Johnson and Jones 1977, Johnson and McCormick 1978, Swanson 1979, Johnson et al. 1985). The policy of the various management agencies were explained by Almand and Krohn (1978) (BLM), Barry (1978) (SCS), Davis (1978) (EPA), Hirsch and Segelquist (1978) and Spear (1985) (Fish and Wildlife Service), McGuire (1978) (Forest Service), and Jones et al. (1978) (Bur. Reclamation). These objectives have been strengthened by the adoption of the National Environmental Program. Knopf et al. (1988) made the following recommendations:

- 1) That Congress assign enforcement powers to the Fish and Wildlife Service that would extend across all agencies,
- 2) Review user fees for riparian areas to ensure that wildlife values are reflected,
- 3) Each agency should develop and make public specific guidelines for riparian areas to reflect regional rather than only local planning,

- 4) Agencies coordinate management within an identified drainage, and
- 5) Agencies develop new technology to discourage the spread of exotic woody plants within riparian systems.

4. Mitigation.--The mitigation of fish and wildlife losses caused by federal or federally approved water projects was initiated by Congress in 1934 but for many years was treated as a "consult and ignore" obligation. The policy was strengthened over the years, particularly during the Carter administration. Mitigation, especially "loss prevention," is now an integral part of planning and is a continuing obligation during the implementation of projects (Krulitz 1979). However, Cutler (1979) acknowledged that mitigation is often an afterthought, is often an attempt to correct a mistake, and is in part a failure. He emphasized that a holistic approach which considers the welfare of wildlife and balances environmental and economic values was most beneficial. Jahn (1979) pointed out the growing dissatisfaction with the unconstrained market system in allocating uses of resources such that values important to society are degraded or destroyed. In summarizing the national symposium on mitigating losses of fish and wildlife habitats, he made extensive recommendations for improving mitigation. In southwestern riparian areas, revegetation can be an effective method of mitigating loss of wildlife habitat (Anderson and Ohmart 1979).

5. Control of Harmful Exotic Plant Invaders.--The invasion of two species of foreign woody plants, saltcedar and Russian olive, poses one of the most serious threats to the plant and animal communities in southwestern and western riparian areas. The invasion and effects of Russian olive were described by Knopf and Olson (1984). This plant is not a subject of the present review and control proposal, but its nature would allow it to be a prime candidate for biological control in some future program if conflicts of interest are not too great.

The invasion of saltcedar in the 1930's (Robinson 1965; Horton 1977) is probably the single most important threat in southwestern riparian ecosystems. Not only does it displace native vegetation directly but it interacts in a synergistic manner with many other factors (lowered water tables, altered stream flow regimes, fire, overgrazing by livestock) to increase their destructive influence.

The mechanical and herbicidal methods used to control it are of such a broad spectrum that practically all vegetation is destroyed by the effort. In many cases, the control is worse than the saltcedar had been, and the opposition of environmentalists that blocked many control programs has been encountered.

Saltcedar is ideally suited to biological control through the introduction of natural enemies (mostly insects) that attack it and are specific to it within its native distribution in Asia. Unfortunately, the only inquiry into its potential for biological control (Watts et al. 1977) looked only at the potential use of North American insects and did not consider the most obvious and many times proven procedure of introducing foreign insects. This report naturally concluded that biological control had little or no potential for success. This attitude has, therefore, persisted in the literature and in planning options since. The excellent potential for successful biological control is discussed in detail in other sections of this report.

Several destructive, invasive foreign weeds have been controlled in the United States, Canada and several other countries by biological control. The effects of biocontrol have been to replace weed stands with diverse plant communities, with the weed species remaining as a minor component of the plant community (Harris 1988).

### E. Effects of Saltcedar in Parks and Other Protected Areas

Saltcedar has invaded riparian areas of many state and national parks, recreation areas, and wildlife refuges in the western United States. These are the areas most heavily utilized by visitors for camping, water sports, bird watching, etc. One of the major objectives of the National Parks Service is to preserve the flora and fauna of the area in its natural state. The invasion of saltcedar has seriously compromised this objective. However, the use of herbicidal, mechanical or fire controls also would seriously damage these areas as well as being very costly, and all would require repeated applications. Biological control, by the introduction of control organisms from the site of origin of saltcedar would offer almost the ideal solution to the saltcedar invasion in parks and wilderness areas. The only drawback is that the released control agents would likely control saltcedar in all areas, including areas where it has some beneficial values. Geographically isolated areas would, however, have considerable protection against discovery by the control agents.

Two opinion surveys have been made of parks managers and administrators (1978 and 1989) and a symposium was held in 1987 regarding the effects of saltcedar in parks.

1. Tiernan Survey.--In 1978, Charles Tiernan of the USDA Forest Service conducted an opinion survey concerning saltcedar in parks and other agencies. His mail questionnaire inquired about the scope of the saltcedar problem but was primarily aimed at obtaining an opinion as to whether or not the managers of these areas favored a biological control program. The questionnaire asked:

- 1) What is the extent of the Tamarix problem in your area?--
- 2) Do you have any objections to the use of biological control to reduce the rate of spread?
- 3) How might these objections be resolved?
- 4) Would you support a trial introduction to test biological control of saltcedar on your land?

The following 44 replies were received:

National Parks Service	6
Bureau of Land Management	4
Fish and Wildlife Service	2
Bureau of Reclamation	2
Indian Tribal Councils	13
Forest Service	13
State departments of agriculture	3
University	1

The 38 replies that provided information on the questions are summarized as follows:

Favored biocontrol provided the insects are specific to saltcedar, that proper testing was done, and that National Parks Service policy allowed the introduction of control agents	21
Had little saltcedar and had no opinion	7
Favored biocontrol but had reservations about the effects on wildlife; some wanted control in some areas but not in other areas	8
Did not want to participate (no reason given) (from an Indian reservation)	1
Did not want because of possible interference with recreational areas (from a National Forest)	1

The positions of the various agencies were as follows:

#### Bureau of Reclamation

Texas--Favor reducing growth rate of Tamarix with biocontrol, concerned about specificity, can control be stopped?

Utah--Generally favor control, concern about specificity and there will be some objection to damage of wildlife habitat.

### Bureau of Indian Affairs

Phoenix Area Office--Contacted 28 agencies in Arizona and Nevada; 22 of these had no appreciable acreage of saltcedar or no interest in biological control. Six agencies reported 63,800 acres infested and 5 of these favored biocontrol. Summarized in letter from Asst. Area Director, Phoenix, AZ, 20 July 1978.

Albuquerque Area Office--Saltcedar is a problem on the Ute Reservation, CO, and in the 10 Southern Pueblos--6160 acres infested. Tribal officials interested in biocontrol--summarized in letter from Area Director.

Navajo Area Office--Saltcedar infests 40,000 acres, getting worse. Support biocontrol if insects are host specific.

Other--Letter from Northern Pueblos Agency (don't know what Area this is); saltcedar not a pest but they support biocontrol.

### State Departments of Agriculture

Nevada--Letters from Division Plant Industry, 30 March 1978, summarizes their position. Attached letters from Nevada Division Forestry (want control), State Parks (saltcedar not a problem), Fish and Game (interested in biocontrol).

Utah--Letter from Commissioner of Agriculture, 31 March 1978. Want biocontrol but be sure of host specificity, etc.

Other--Another letter from Department Range Science, Utah State University, Logan--favors biocontrol.

### National Park Service

Replies to questionnaires were received from 5 national parks, 3 in Utah, 1 in New Mexico, and 1 in Arizona; in addition, the Western Region Director replied.

The WR Director recognized saltcedar as a great and increasing problem in the parks. He would appear to favor biocontrol except that current policy states that all exotic species are to be eliminated wherever feasible--this prohibits saltcedar and any biocontrol agents! This policy was under review (1978) with a proposal that exotic biocontrol agents species could be introduced provided they themselves did not become harmful. He also would not permit experimentation on parklands. However, once controls were developed, and if the above policy were changed, he would welcome their release.

The letters from the park superintendents were unanimously in favor of the concept of biocontrol of saltcedar. Only Petrified Forest, AZ, and Arches, Canyonlands, Natural Bridge, UT, had significant acreages but all recognized the danger of spread and increase. Carlsbad-Guadalupe, NM, did not want biocontrol because they have so little they can control it by hand and recognize the policy against exotics. Arches Canyonlands, Natural Bridge, UT, enthusiastically supported trial introductions. Capitol Reef, UT, also would support release but would want more information first.

### Fish and Wildlife Service

Utah--Have 4400 acres infested, would favor biocontrol, above control methods now in use. Concern about wildlife areas.

New Mexico, Texas, Oklahoma, Arizona--Extensive infestations, most are wildlife areas, do not consider Tamarix a great problem, would favor thinning stands.

### Bureau of Land Management

Received replies from Nevada, Arizona, Utah, and New Mexico.

Nevada--No objection to control but must be careful of adjacent private landowners.

Arizona--Great problem here. No objections to biocontrol but must be specific.

New Mexico--Very little on BLM land. No objections to control but be careful of wildlife habitat.

Utah--Many areas infested. Would want control in some areas, not in others because it is good wildlife habitat. Concerned about specificity.

### National Forest Supervisors

Of the 5 National Forests in Arizona, 2 had little or no saltcedar and no opinion, 1 favored biocontrol if specific, 1 thought the Arizona Fish and Game Dept. might be opposed because of the white-winged dove, and 1 thought their area was too close to a large city and too visible for a test area. Of the 5 Forests in New Mexico, 2 cited the need for an Environmental Assessment and, if controlled, for revegetation of native plants. One stated that saltcedar was good wildlife habitat but that native plants were better. One thought control might interfere with recreation, and 1 had no saltcedar and gave no opinion. Of the 3 Forests in Utah, all had little or no saltcedar but one favored biocontrol.

Since the time of Tiernan's survey, the extensive studies of Bertin Anderson and Robert Ohmart have demonstrated the detrimental effects of saltcedar on nearly all wildlife except the white-winged dove. The situation in national parks was reviewed again in 1987, and the economic effects of saltcedar in parks was reviewed in 1989, as discussed below.

2. Tucson Symposium.--Kunzmann et al. (1989) reported on the Tamarix Conference held in Tucson, AZ, September 1987, sponsored by the National Parks Service and the University of Arizona. Papers were presented describing saltcedar infestations, effects and control in 12 national parks, monuments, wildlife areas, and recreational areas. Six of these had extensive infestation along rivers and tributaries, around springs and seeps, or along lake shores. Several workers mentioned that saltcedar had reduced drinking water sources for wildlife at springs and that controls has been initiated to increase these water supplies and also to clear campsites. The following problem areas were cited:

Big Bend National Park--In 1976, 74 of 81 (91%) backcountry water sources were infested with saltcedar; in 1986, 150 of 227 water sources surveyed were infested (66%), plus extensive, dense infestations along the Rio Grande (Fleming 1979).

Lake Mead National Wildlife Area--95% of the springs have saltcedar around them (Burke 1989).

Zion National Park--Saltcedar on most watercourses and at some springs. Dense saltcedar stands for 7 miles of the Virgin River. Floods control saltcedar on some fast streams but lowland streams have dense thickets (Hays and Mitchell 1979).

Death Valley National Monument--20 known stands of 0.1 to 160 acres each, sparse to dense stands; both saltcedar and athel present and damaging; severely limit drinking water for wildlife. A pond of several acres in 1950 dried up as Tamarix increased, but after control in 1971, water table rose 1.5 ft and a pond of 1 acre reappeared 8 weeks later; today, several pools larger than 1 acre are present and wildlife has returned (Rowlands 1989).

Canyonlands and Arches National Parks and Natural Bridges National Monument--Many areas of dense, pure stands along shores of Green and Colorado Rivers, 27% reduction in width of Green River with increased flooding. Most tributaries and a majority of the springs, seeps, potholes, and intermediate drainages are infested with saltcedar. Several off-park impoundments are infested and provide constant seed source (Thomas and Kitchell 1989).

Grand Canyon National Park--Sand beaches along river became densely infested after completion of Glen Canyon Dam in 1963 halted seasonal floods. However, these areas now have some wildlife and provide shade for boaters, ~~and will not be controlled~~. Infestation<sup>s</sup> on tributaries and at Grand Canyon Village will be controlled (Sharrow 1989).

Glen Canyon National Recreation Area--Of 1822 mi shoreline, 475 mi have beaches suitable for saltcedar infestation. Lake filled only in 1980 and previous infestation<sup>s</sup> were killed by flooding. Young stands becoming established. The 13 mi along the Colorado River between Glen Canyon and Lee's Ferry, is in dense saltcedar, 30-40 years old (Holland 1989).

Wupatki National Monument -48 sites infested with tamarisk plus 17 sites with both tamarisk and camelthorn (Cinnamon 1989).

Joshua Tree National Monument--Natural water sources rare. Saltcedar infests 14 locations, 12 of these are also infested with athel (Coffey 1989).

Organ Pipe Cactus National Monument--2 of 5 springs examined were infested, plus old establishment along Sonoyta River (Mikus 1989).

Petrified Forest National Park--infestations of unrecorded size along Puerco River and Dry Wash (Bowman 1989).

Guadalupe Mountains National Park--only a few, scattered trees but infested areas outside of park provide seed source (Davila 1989).

All of these areas have initiated control measures in recent years and some have been attempting control for many years. The most common method was to cut the trees close to the ground and treat the stumps with a 2,4-D:Picloram mixture or with triclopyr, which had given 80-95% control in several cases (Neill 1989). Some workers reported good control by burning

but most of these reports were at the end of the first year and regrowth is almost certain to occur in subsequent years.

Arsenal (imazapyr) has been used recently in some areas. It must be used with great caution because it has a very broad spectrum (see Sect. XVII,A,1,e of this report). Most workers reported that surveys were in progress to discover new infestation and that control efforts would continue as funding permitted. The final summary recommended that a bibliography of saltcedar should be prepared and that the distribution and density of saltcedar in the U.S. needs to be measured to update the "best estimate" compilation of Robinson (1960). The report also recommended further research on the ecology of saltcedar and on the development of more effective controls, especially of biological control (Bennett and Burke 1989).

3. Brown Survey. -In 1988-89, F. Bruce Brown of Great Western Research, Mesa, AZ, conducted personal and telephone interviews with park and regional managers of 39 state and national parks and wildlife refuges in Arizona, California, Colorado, New Mexico, Texas, and Utah. The purpose was to gather information on the extent of the saltcedar infestation in these areas, the type and extent of interference caused, and any beneficial aspects in order to perform an economic analysis of saltcedar impacts (Brown 1989).

In a sample of 8 state parks, 4 had programs for saltcedar control and were spending \$28,000 annually, and one had plans for a control program. Of 6 national parks and wildlife refuges sampled, 5 had control programs with an annual cost of \$46,000. Two had no saltcedar but all the others stated that they would increase their control efforts if funds were available.

The most frequent problems and benefits associated with recreational use of saltcedar infested areas were (number of respondees from 12 questioned):

	<u>Problem</u>	<u>Benefit</u>
Access to recreational areas	6	
Mosquitoes and noxious insects	5	
Allergies to pollen	4	
Dust	3	
Boating hazard	3	
Aesthetic	2	
Fire	1	
Shade		5

Saltcedar thickets frequently restricted access to shade, picnic areas and campgrounds. Mosquito problems were increased when saltcedar impeded water drainage and created breeding sites. Many persons appeared allergic to saltcedar pollen, which was mostly produced during periods of peak recreational activity (Potter and Pattison 1976). Also, large amounts of dust collected in saltcedar thickets in some areas.

The shade provided by saltcedar was considered beneficial in several parks in the Arizona and California deserts. However, visitors increasingly use man-made shelters in parks rather than natural shade, and the recreational vehicles used often eliminate the need for shade. Several parks trimmed or removed saltcedar thickets to make areas more usable.

All of the 14 managers interviewed stated that at least one type of native riparian vegetation was superior to saltcedar for recreational purposes and 10 of the 14 preferred all types of native vegetation to saltcedar. The native vegetation, especially the most preferred mature cottonwood-willow type, provided much shade while the relatively open understory allowed access for recreation. Cottonwood-willow is also the most preferred habitat of birds and other wildlife while saltcedar ranks near the bottom.

Brown (1989) estimated that 217,000 user-days occurred in saltcedar infested areas within the 4 parks and one wildlife refuge examined, and users spent \$24.7 million in saltcedar infested areas. He found only one

case in which data demonstrated the economic effects of controlling saltcedar on park usage. At Roper Lake State Park in southeastern Arizona, 22% of the 300 acres in the park was infested with saltcedar, ca. one-fourth of this in moderate stands and the rest in dense stands. After a 100% control effort, the number of campsites could be increased and annual visitation increased from 50,000 to 66,500, an increase of 33%.

Brown (1989) suggested that a biological control program that reduced saltcedar by only 50% would increase visitor usage by only 1-5% but that a 90% effective control would increase usage by 20% and 100% control would provide a 30% increase in usage. This would provide annual benefits of \$0.7 million for 50% control and from \$2.3 to \$7.0 million for 90% control.

#### F. Impact of Biological Control on the Riparian Plant Community

As discussed above (Sect. IV,VI), the invasion of saltcedar since the 1920's and 1930's has devastated the native flora and fauna in many western riparian areas. The completeness of the displacement of native plants has been greatly accentuated by other factors that have interacted with saltcedar, such as burning, salt accumulation, damming and changing annual flow regimes of rivers, lowering water tables, woodcutting, and other factors, even including some of the control programs. This invasion has greatly decreased plant diversity in the affected areas, and the abundance of many formerly dominant species such as cottonwoods, willows, screwbean mesquite, seepwillow, and many other plant species. This description of the plant community is contrary to the purpose of the National Parks Service, State Parks Departments, and of many private organizations to conserve native plant communities, at least within parks. The conversion from mixed native species to saltcedar has also been detrimental to many species of wildlife, especially birds, as discussed in Sect. VII of this report.

The expected effects of a biological control program to control saltcedar is that dense stands of saltcedar would be reduced in canopy cover and other vegetation would grow in the interspaces. The type of effect on saltcedar, whether a reduction in foliage, killing of small trees or large trees, reduction in reproduction and reinvasion, etc., would be determined by the type of control agents used. The type of replacement vegetation would vary with the geographic area but, in general, would be expected to be the same as that occurring before saltcedar invaded, unless the physical structure (soil salinity, depth to water table) has changed. Biological control would increase the diversity of plant species and structural types that, in general, would favor native birds, mammals, and other animal species. Under these conditions, a 50% effective biological control program would probably have a large beneficial effect, more so than with several other factors examined in this report. A 90% effective control program would produce much more opening of the stands and allow a growth of replacement vegetation near the pre-invasion condition, with patches and scattered trees of saltcedar remaining.

Brown (1989), through conversations with various federal, state and private biologists, assembled information for the necessary assumptions to conduct an economic analysis of plant community and wildlife aspects of a saltcedar biological control program. Since ecological values do not lend themselves well to a quantitative (dollar) analysis, he produced a qualitative analysis. He assumed that along the Lower Colorado, Salt and Gila Rivers, natural replacement vegetation would be 90% arrowweed and only 10% saltbush-mesquite woodland. Arrowweed is of negligible value for wildlife while saltbush-mesquite has a relatively high value. Replacement in this area by native species would be a slow process because of climate

and soil condition and depth to the water table. He assumed that in New Mexico and Texas, replacement vegetation would be 60% arrowweed and 40% saltbush-mesquite. In the Upper Basin states, it would be 60% scrub willow and 40% cottonwood-mixed deciduous forest. He did not explain why the wildlife workers expected the replacement vegetation to be different from the original vegetation before saltcedar invaded. This would be of special concern in the case of arrowweed which tends to grow mostly in moist areas and might invade deltas above reservoirs formed by saltcedar sedimentation, such as above Lake McMillan on the Pecos River in New Mexico, or marshy areas along the Lower Colorado River. In areas along the Salt-Gila River, the problem is more of a low water table and high salt accumulation in the surface soil.

Brown (1989) examined the effect of the baseline impacts of saltcedar, and of a 50% and 90% effective biological control program, on 26 species of the more common native plants of southwestern riparian areas. He evaluated impacts as follows:

	<u>Number of plant species affected</u>		
	<u>Negatively</u>	<u>Positively</u>	<u>Strongly positively</u>
Baseline impact	25	0	0
50% control	0	9	0
90% control	0	17	9

Even these estimates seem conservative in some cases. The present impact on cottonwoods, seepwillow and willows may be more serious and the benefits from control greater than listed by Brown (1989).

Brown (1989) also examined the impacts of saltcedar on 16 sensitive or rare plant species. One species, red rock tarweed (Hemizonia arida), was impacted by saltcedar and would be very beneficially affected by biological

control but he found ~~no impact on~~ the other 15 species. However, the potential exists for much greater harm to rare and endangered species of riparian areas than discovered to date. This damage could come either from severe competition from saltcedar, by the increased soil salinity or sedimentation caused by saltcedar, or by the herbicides used to control saltcedar (see Sect. XVI, this report). Damage may have occurred to some rare species during the saltcedar invasion of the 1920's and 1930's before environmental concern developed.

#### G. Conclusions

Replacement of native plant communities, and the consequent degradation of habitat for most species of birds, and for mammals and other vertebrates, is the most obvious and the best documented effect of saltcedar invasion. The saltcedar invasion is one of the most, if not the most, important factor in riparian habitat degradation in the Southwest. It is not, however, the only factor. Other very important factors are: 1) lowered water tables caused by pumping groundwater, 2) clearing land for agriculture and urban expansion, 3) modification of the seasonal flow of rivers and permanent flooding caused by dam construction, 4) overgrazing by livestock, 5) fire and several other less important factors such as woodcutting and recreation.

Unfortunately, the particular biology and ecology of saltcedar allows it to interact with several of these other factors to increase their destructiveness, or they interact to increase the dominance of saltcedar. Saltcedar uses large amounts of water that could be used by other vegetation (although its effect on downstream flow has been difficult to measure) thus worsening the effect of excessive pumping of groundwater.

Fire easily kills cottonwoods and also kills other beneficial trees and shrubs but only kills the top growth of saltcedar. After fires, saltcedar

rapidly acquires dominance over other vegetation. The near elimination of flooding and the shift in seasonal high water release from the natural spring cycle to later in the summer strongly favors saltcedar over cottonwood, willow and other native plants. Livestock readily feed on cottonwood, willow and other native tree seedlings and completely stop regeneration of these species in overgrazed areas; however, saltcedar is not very palatable to livestock and it gains a competitive advantage through grazing.

Traditional mechanical and herbicidal controls for saltcedar are costly and also destroy all or most of the other vegetation as well. Biological control would greatly reduce or eliminate the need for herbicides or mechanical controls to clear or maintain cleared areas or for the channelization and clearing of floodways. Biological control has great potential for successful reduction of the density of saltcedar. By this method, control of saltcedar would be the easiest, least costly and the least in conflict with other interests of all the factors that destroy riparian areas (lowered water tables, dams, livestock grazing, etc.). In addition, saltcedar control would partly alleviate the destructiveness of several of these other factors. This is not to say that other action to reduce the effect of the other factors is not necessary. Lowered water tables and overgrazing <sup>-may, could?</sup> prevent the reestablishment of native vegetation even if saltcedar is controlled.

Numerous attempts to re-establish native trees and shrubs after clearing saltcedar, especially on the Rio Grande in New Mexico and the Lower Colorado River, have shown that good results can be obtained if proper sites are selected and proper planting and maintenance procedures are followed. Cottonwoods, willows, mesquite, palo verdes, quailbushes, and inkweeds have been used successfully; selections for improved survival and growth rate have

been developed; and both container-grown plants and poles planted down to the water table have been used. Careful site selection is important to success and should consider depth to the water table, soil and groundwater salinity, and soil type. Irrigation is critical to establishment of container-grown plants, and protection from browsing (by livestock and wildlife), removal by beavers, and insect and weed control are important. Costs range from \$600 to \$3800 per acre, depending on the site and the methods used; this could be reduced by careful site selection, better methodology, and on larger-scale projects. Successful revegetation (natural or cultivated) can replace saltcedar with fewer trees, reduce flooding, possibly reduce groundwater water usage, and at the same time greatly improve wildlife habitat. Revegetation should be considered a viable option to improve wildlife habitat if the natural vegetation does not return naturally and quickly enough after saltcedar control.

Better management of riparian areas, revegetation, and land acquisition will still be necessary but the effect of removing saltcedar as a major part of the riparian problem (though leaving it as a lesser part of the plant community) will greatly enhance the effectiveness of the other measures to the overall improvement of the riparian ecosystem.

## VII. EFFECTS OF SALT CEDAR ON WILDLIFE

### A. Non-Game Birds

1. Value of Riparian vs. Other Areas.---In semi-arid southwestern North America, riparian habitats are of great importance to many species of birds, since these are often the only areas where food (seeds or insects), nesting sites and water are available.

One of the greatest and best documented threats posed by the invasion of saltcedar in riparian ecosystems is the displacement of native vegetation that is essential or at least superior, habitat for many species of wildlife, especially of birds. Johnson et al. (1977) classified the 166 nesting bird species of southwestern lowlands as follows:

	<u>No. species &amp; % of total</u>
Obligate riparian	43 (26%)
Preferential riparian	43 (26%)
Wetlands and obligate riparian	31 (19%)
Wetlands	4 ( 2%)
Suburban and agricultural	6 ( 4%)
Non-riparian	39 (23%)

In New Mexico, the Gila River supports 112 and the San Juan River supports 105 breeding bird species, or 16-17% of the breeding species of temperate North America, within a distance of only a few score miles (Hubbard 1977).

The five-year Verde River, AZ, study that began in 1969 demonstrated that riparian habitats support higher population densities of birds than any other forest habitat type (Carothers 1977). Carothers et al. (1974) reported 847 breeding pairs per 100 acres in cottonwood along the Verde River and Carothers and Johnson (1975) reported 605 pairs, also in cottonwood in Arizona, which had been 1058.8 pairs per 100 acres the year before the habitat was disturbed by urbanization. Stamp (1978) counted 684 breeding

pairs per 100 acres of 28 species in cottonwood and 244 pairs per 100 acres of 19 species in mesquite along the Verde River.

This study also shows that vegetation manipulation was extremely harmful to breeding bird populations, the extent of impact being proportional to the degree to which phreatophytes were removed (Johnson 1970, Carothers and Johnson 1971). On the Verde River, bird densities were as follows:

Partly cleared (10 trees/A)	580 pairs/100 A
Less cleared (26 trees/A)	939 pairs/100 A
Uncleared (46 trees/A)	1322 pairs/100 A

Studies in 7 paired riparian vs. non-riparian sites in Arizona demonstrated that riparian sites are very important stopover habitat for spring migrant passerine birds (Stephens et al. 1977). Bird densities averaged 2.78 times greater in the riparian sites than in the non-riparian among 28 species of birds observed; insectivorous species were 8.1 times more abundant in the riparian sites, but granivorous species were 1.1 times more abundant in the non-riparian. Number of species averaged 2.3 times more in the riparian sites, with little difference between insectivores and granivores.

Szaro (1981) compared 3 habitat types for bird usage in the Tonto National Forest in central Arizona:

	<u>Breeding species</u>	<u>Density/ 40 ha</u>
Riparian strip	13	321
Uncleared chaparral	9	103
Cleared grassland	4	24

The Rio Grande corridor from "Big Bend" eastward to Lake Amistad (a 250-mile reach) is an important migratory route for birds, especially because of its relatively stable vegetation (Wauer 1977) although even this area has been seriously invaded by saltcedar. Of the 94 bird species known to breed within riparian systems of the Southwest, 40% breed here. Several species, such as the peregrine falcon and Bell's vireo which are rare in

other areas, find refuge here. The social parasitic cowbird that invaded after 1909 has apparently extirpated the yellow warbler, but other attacked species that have been heavily parasitized in other areas remain common here.

Water birds are strongly influenced by river channel modifications and by heavy human usage of the habitat. Tolerance of these factors varied greatly among different groups of water birds (Anderson and Ohmart 1984a):

	<u>Channel modification</u>	<u>Human usage</u>
Diving ducks	tolerant	tolerant
Loons and greebes	?	?
Gulls	tolerant	tolerant
Coots and gallinales	reduced	reduced
Puddle ducks	intolerant	intolerant
Shorebirds	most intolerant	most intolerant

2. Birds of the Lower Colorado River, Arizona and California.--Probably the most comprehensive study of the relationships between wildlife species and vegetation types was conducted along the Lower Colorado River from 1972 to 1984 and summarized by Anderson and Ohmart (1984a); this project was funded by the USDA-Bureau of Reclamation. The objectives were to develop knowledge to recommend ways in which vegetation could be managed to: 1) reduce water loss by evapotranspiration, 2) reduce total vegetation at heights of 4-6 ft so that flood flows could pass unhindered, and 3) explore the feasibility of revegetation. All of these objectives ultimately were to be blended with wildlife enhancement. The study so far has generated 48 research papers in addition to the final 529-page report. The number of each bird species in each vegetation type and for each season of the year were given by Anderson and Ohmart (1977b).

The vegetation was characterized into 6 community types and 6 structural types (Anderson et al. 1977b). The 6 community (species) types are as follows:

- CW = cottonwood-willow (Populus fremontii and Salix gooddingii) constituting at least 20% of the trees.
- HM = western honey mesquite (Prosopis glandulosa torreyana) that, according to Burkart (1976), is a subspecies of the honey mesquite (P. glandulosa) cited in Anderson and Ohmart's various studies; it occurs along the lower Colorado, the lower Gila and the Salton Sea areas (R. M. Turner, U.S. Geolog. Surv., Tucson, AZ, pers. comm.). HM constitutes 95-100% of the trees.
- SC = saltcedar (Tamarix chinensis or T. ramosissima) - 95-100% of the trees.
- SB-SC = Screwbean mesquite (Prosopis pubescens) - saltcedar, with screwbean constituting at least 20% of the trees.
- HM-SC = approximately equal number of velvet mesquite and saltcedar.
- AW = arrowweed (Tessaria sericea) - 95-100% of the total vegetation in the area.

The 6 structural types were based on foliage volume at heights of 0.6, 1.5, 3.0, 4.5, 6.0, and 9.1+ meters (2, 5, 10, 15, 20, and 30+ feet) (Fig. 10).

Structural Type I was the most dense overall and was characterized by the amount of volume over 9 m (Fig. 10) although there were relatively well developed layers below the 9 m level. Type II was characterized by having less vegetation above 9 m but more volume between 3.0 and 6.0 m than Type I. The other types were mainly characterized by having less volume at higher layers and more at 0.0 to 0.6 m (Fig. 10) (see also footnote to Table 2).

The entire Lower Colorado floodplain was then mapped by community-structural type (Anderson and Ohmart 1984b). They established 75 miles of transects, along which 1156 subplots (each 150 x 15 m) were established where measurements were made. Not all communities contained all 6 structural types, and 29 community-structural types were represented in the study.

In 1981, the Lower Colorado River floodplain from Davis Dam near the Arizona-Nevada border to the U.S.-Mexico border contained 111,692 acres of riparian vegetation. The dominant community types often contained trees of other species; when these were computed and summed, the total area in each

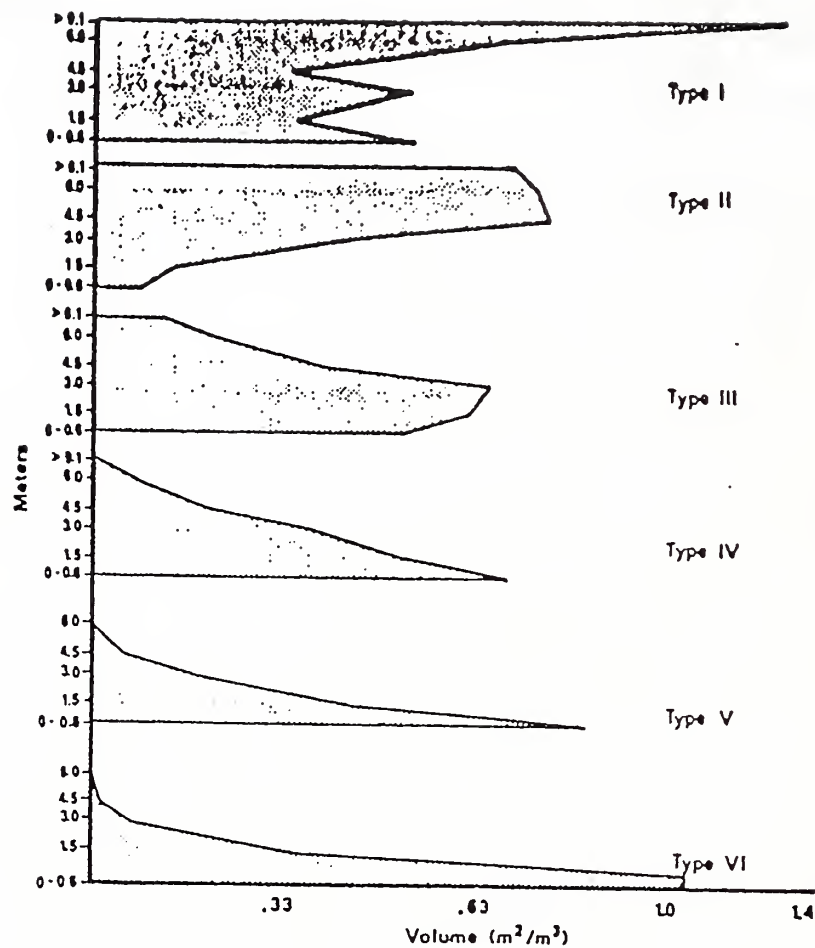


Fig. 10. Foliage volume characteristics of structural types (from Anderson et al. 1977b, Fig. 2).

species was obtained, which in the case of saltcedar was 56.91% of the area (Table 8) (Anderson and Ohmart 1984b).

Anderson and Ohmart (1984a) recorded the occurrence and seasonal abundance of 385 species of birds in the various plant community types in the riparian area plus those in open water, the river, marsh, desert, agricultural land, and urban areas.

Table 8. Total areas of riparian vegetation along the Colorado River, AZ and CA, from Davis Dam to the Mexican border.<sup>a/</sup>

Dominant community type	Total acres	Mean % of total trees				
		Salt-cedar	Western honey mesquite	Screwbean mesquite	Cottonwood-willow	
Cottonwood-willow	8,542	60	51.25	1	25	4.35
Screwbean mesquite-saltcedar	24,497	59	2	38	1	21.93
Western honey mesquite	14,131	0	99	1	0	12.65
Saltcedar-western honey mesquite	9,564	54	46	0	0	3.56
Saltcedar	39,218	99	0	1	0	35.11
Arrowweed	4,242					3.80
Marsh	10,678					9.56
Atriplex	597					5.35
Inkweed	223					2.00
TOTAL ACRES <sup>b/</sup>	111,692	63,568 <sup>b/</sup>	18,964 <sup>b/</sup>	6,367 <sup>b/</sup>	3,235 <sup>b/</sup>	106.79
% OF TOTAL ACRES	45,219 <sup>ka</sup>	56.91	16.98	5.70	2.90	6.61
		25,736 <sup>ka</sup>	7,678 <sup>ka</sup>	2,578 <sup>ka</sup>	1,314 <sup>ka</sup>	

<sup>a/</sup> From Anderson and Ohmart (1984b), his summary table and Table 3.

<sup>b/</sup> Percent of given species X acreage in each community type, summed.

The avian community was described by 9 variables (Anderson and Ohmart 1984a):

- 1) Total species richness
- 2) Number of species of permanent resident insectivores
- 3) Number of species of visiting insectivores
- 4) Density of permanent resident insectivores
- 5) Density of visiting insectivores
- 6) Density of Gambel quail
- 7) Density of doves
- 8) Density of passerine granivores
- 9) Density of frugivores

The vegetation was characterized by 15 variables:

- 1-4) Foliage density at 0.2-0.6 m, 1.5-3.0 m, >4.5 m, and total
- 5-8) Patchiness at the same heights
- 9) Foliage height diversity
- 10) Number shrubs per acre

*100 = 39,372 m*

- 11) Number western honey mesquite per acre
- 12) Number western honey mesquite with mistletoe per acre
- 13) Number screwbean mesquite per acre
- 14) Number cottonwood-willow per acre
- 15) Proportion of total trees which were saltcedar.

The data were analyzed by "principal components analysis."

The greatest densities of birds were in orchards, western honey mesquite, cottonwood-willow and screwbean mesquite and the lowest densities were in saltcedar, arrowweed and desert wash areas; densities varied from season to season and western honey mesquite had the greatest density during the more critical winter period. For the entire year, saltcedar had only 59% of the mean density of birds as the cottonwood-willow, screwbean and western honey mesquite communities (the three communities most affected by saltcedar invasion). During the winter, saltcedar had only 39.1% the density of birds as the others (Table 9).

The greatest number of species of birds was in cottonwood-willow, followed by screwbean and western honey mesquite. For the year, saltcedar had only 75% as many species as the average of cottonwood-willow, screwbean and western honey mesquite, and only 47.6% as many species during the winter; only arrowweed ranked lower than saltcedar during the winter (Table 9).

Their analysis showed that, overall, avian groups were associated more with foliage density and diversity (including cottonwood-willow trees) than any other vegetation variable; also, 6 of the 9 avian groups increased as western honey mesquite increased. Birds seemed to avoid vegetation with many saltcedar trees and saltcedar was the most important negative variable in spring, fall and winter. Overall, no avian group increased as saltcedar increased, but 4 of the 9 groups decreased as saltcedar increased (Table 10).

Table 9. Comparison of total densities (number per 40 ha) and number of species of birds in 4 plant community types in the Lower Colorado River Valley, December 1975-November 1976 (from Anderson et al. 1977a, Table 4 and 6).

Community	Dec.- Feb.	Mar.- Apr.	May- Jul.	Aug.- Sep.	Oct.- Nov.	Total	
-----Total densities-----							<i>Pew</i>
Cottonwood-willow (CW)	148	172	336	262	210	1128	<i>986</i>
Screwbean mesquite (SB)	73	109	318	307	183	990	<i>917</i>
Western honey mesquite (WHM)	193	193	323	195	270	1174	<i>986</i>
	<i>Σ = 138</i>						<i>58 95</i>
Saltcedar-WHM	42	111	295	184	177	809	
Saltcedar	54	71	216	177	129	647	<i>59</i>
Desert wash	68	115	176	118	185	662	
Arrowweed	18	23	124	141	99	405	
Orchard	158	158	678	540	135	1669	<i>151</i>
% Saltcedar of mean of CW+SB+WHM	<i>54 / 138 = 39.1%</i>						
	46.4	66.3	69.5	58.4	58.96		
-----Number of species-----							(mean)
Cottonwood-willow (CW)	28	40	35	41	34	35.6	<i>37.2</i>
Screwbean mesquite (SB)	16	27	24	33	26	25.2	<i>27.5</i>
Western honey mesquite (WHM)	19	30	22	28	27	25.2	<i>26.5</i>
	<i>Σ = 21</i>						<i>30.2</i>
Saltcedar-WHM	16	20	20	19	22	19.4	
Saltcedar	10	19	25	27	26	21.4	<i>24.2</i>
Desert wash	16	20	20	21	30	21.4	
Arrowweed	8	13	21	23	18	16.6	
Orchard	17	20	18	25	17	19.4	
% Saltcedar of mean of CW+SB+VM	<i>10 / 21 = 47.6%</i>						
	47.6	58.8	92.6	79.4	89.7	74.67	
-----Species plus density-----							
% Saltcedar of mean of CW+SB+VM	43.4	52.6	79.4	74.4	73.6	66.82	

Table 10. Patterns of vegetation use by avian groups on the Lower Colorado River (from Anderson and Ohmart 1984a, pg. 183-186).

	DD	WHS	SC	DL	SB
Total species richness	++	+	-		(+)
Species perm. res. <sup>insect</sup> insectivores	+	+	-		
Species visit <sup>insect</sup> insectivores	+++	+, -			(-) ?
Density visit insectivores	+				
Density perm. res. insect <sup>insect</sup> insectivores	+	+		-	+
Density doves				-	+
Density Gambel quail		+	-	(+) ?	
Density pass. granivores		+		-	
Density frugivores		+	-		

DD = Total foliage density and diversity and number of cottonwood-willow trees.

WHS = Densities of western honey mesquite, mistletoe and shrubs.

SC = Saltcedar.

DL = Foliage density and diversity at 0 to 0.6 m.

SB = Density of screwbean mesquite.

The vegetation requirements of certain avian groups were as follows:

1) The density and number of species of passerine granivores require large numbers of shrubs and avoided high densities of saltcedar and arrowweed at the 0 to 0.6 m level.

2) The Gambel quail was present in high numbers only when quail bush (Atriplex lentiformis) was abundant, especially if near agricultural areas.

3) Permanent resident insectivores require relatively large numbers of cottonwood-willow trees and quailbush.

4) Visiting insectivores require patches of cottonwood-willow and quailbush in above average densities; these were the most important factors in the density-diversity component.

5) Doves preferred trees of varying densities and 15 to 25 feet tall, but trees taller than 40 ft had a negative effect.

6) To attract the greatest number of birds, an area should have shrubs (preferably quail bush) and trees (preferable cottonwood-willow). Inkweed is important to some birds and western honey mesquite with mistletoe is important for frugivores (Anderson et al. 1978).

7) To obtain the greatest number of species of birds, the same factors as in (6) would be required and, in addition, a horizontally patchy habitat would also be important.

Anderson and Ohmart (1984a) emphasized that mature stands of cottonwood-willow are of great importance to many bird species. Along with this, dead snags and branches, a patchy understory of shrubs and emergent plant species (but NOT continuous saltcedar), and an accumulation of leaf or wood litter in some areas is important.

In a 4-year study on the Lower Colorado River (1975-1978), Anderson et al. (1981) found that the most important factor influencing both avian density and species richness was the difference between vegetation types (32% of the variation for density and 45% for species richness) although differences between years and seasons were also significant. Species richness was lowest in saltcedar and highest in cottonwood-willow. Saltcedar consistently contained fewer birds, averaging only 135 birds per 40 ha, while mixed communities averaged 247 birds per 40 ha.

According to Anderson and Ohmart (1984a), the major conclusions from this study were that a management plan should have three components:

a) Include above-average foliage density and diversity and above-average numbers of cottonwood and willow trees. This would attract the avian guild of "visiting insectivores" that was most often associated

with density-diversity and more strongly in summer than in other seasons. This would also strongly contribute to increases in "total species richness" and to densities of "resident insectivores."

★ b) Include mistletoe, which was associated with western honey mesquite and shrubs. This was essential to enhancing populations of frugivores and would also strongly contribute to enhancing the abundance of granivores, quail, doves, permanent resident insectivores, and total species richness.

★ c) Eliminate saltcedar, which would enhance the effect of the first two recommendations. Five of the nine avian groups were negatively associated with saltcedar in one or more seasons. Only the density of visiting insectivores was enhanced at any time by the presence of saltcedar. They speculated that the removal of saltcedar from mixed stands would also enhance avian use.

In the same area (the Lower Colorado), Anderson et al. (1977a) rated saltcedar 6th in overall community value for birds out of eight communities compared. Overall scores were (lower scores = greater value):

Cottonwood-willow	2.47	Desert wash	4.65
Western honey mesquite	3.50	Saltcedar	5.10
Screwbean mesquite	3.83	Orchard	5.27
Saltcedar-western honey mesquite	4.40	Arrowweed	5.47

Saltcedar ranked 7th in total <sup>field</sup> density and in density with 10% doves (they allowed only 10% of the doves counted, estimating that doves got only 10% of their livelihood from the riparian area), 5th in number of bird species, 3rd in bird species diversity, and 7th in community diversity.

In the summer, half of all birds in saltcedar were doves but, even so, more doves were in other communities.

In the areas from Yuma to the Mexican border, Anderson and Ohmart (1977a) found that mean habitat breadth of birds was broadest in summer and narrowest in winter, with less habitat overlap in winter. This suggested that winter was the time of most stress. The permanent residents occupied structural zones more uniformly than visitors, indicating that they were less specialized. Requirements for winter visitors were especially important as they were more highly specialized and were present during the time of greatest stress.

Several bird species are in danger of extirpation from the Lower Colorado River area, mainly a result of the loss of cottonwood-willow habitat and its replacement by saltcedar (Hunter 1984, Calif. Dept. Fish and Game 1988):

106 Gila woodpecker	125 Sonoran yellow warbler
Gilded northern flicker	132 Summer tanager
111 Vermilion flycatcher	Western yellow-billed cuckoo
122 Arizona Bell's vireo	102 Elf owl

not in  
ref

In addition, two other species (brown-crested flycatcher and yellow-breasted chat) and three species he did not study are strongly dependent on cottonwood-willow.

Cohan et al. (1978), in a comparison of 4 vegetation types on the Lower Colorado River, found that a few bird species showed a preference for saltcedar or at least did not avoid it. These were ground feeders, granivores or species that fed largely in other (agricultural) habitats. Insectivores, and especially frugivores, were most intolerant of saltcedar. Insectivores may have avoided it because the sticky exudate might damage the plumage. Frugivores were absent because of the near total absence of fruits and berries.

In the 23,958-acre area he studied, the greatest area was in saltcedar; however, the greatest preference by birds was for cottonwood-willow, and

saltcedar was least preferred:

Habitat type	% of area in habitat type	% of times habitat ranked #1 preference by birds
Cottonwood-willow	10.6	65.4
Screwbean mesquite	28.9	13.0
Western honey mesquite (WHM)	1.0	10.4
Saltcedar-WHM	2.4	3.1
Saltcedar	53.8	7.9

Hunter (1984) noted that half of the bird preference in saltcedar was by the summer tanager and nearly all of that was not in saltcedar but in athel (Tamarix aphylla) which he did not distinguish in his summary. He pointed out that river management practices, flood control and burning all favored saltcedar replacement of cottonwood-willow. Also, these practices favored the increase of starlings, and the nest parasitic cowbird, which further decimated the endangered bird species.

3. The Middle Rio Grande River Valley.--The preference of birds for various vegetative communities was compared along the Rio Grande of western Texas to determine the impacts of various methods of remarking the US-Mexican boundary (Engle-Wilson and Ohmart 1978a).

The defined community types obviously were not pure stands of the dominant plant species, as would be expected. However, the dominant species in some cases was only a very small percentage of the total. For example, the cottonwood-willow type contained only 5, 0 or 1% cottonwood; 14, 9, or 23% willow; and 7, 77, or 39% saltcedar, plus large amounts of seepwillow, grasses and forbs. The seepwillow community contained only a trace of seepwillow but 77% saltcedar, whereas the CW-II community contained 34% seepwillow. The screwbean-V community consisted of only 3% screwbean but 22% wolfberry and 57% forbs. The saltcedar and western honey mesquite communities contained nearly all (or at least very much) of the dominant

species (Table 11). Conclusions regarding bird preference, therefore, must be made with much care.

*OK for other plots*

Table 11. Species composition of the plant communities on the Rio Grande of western Texas (from Engle-Wilson and Ohmart 1978a, Table 2).

Community types <sup>a/</sup>	% canopy cover by major plant species									
	W.honey mesq.	Screw-bean	Cotton-wood	Willow	Salt-cedar	Wolf-berry	Seep-willow	Grasses	Forbs	Bare ground
CW-I	TR	0	5	14	7	0	17	37	36	0
CW-V	TR	0	0	9	77	0	6	15	28	TR
CW-VI	0	0	1	23	39	0	34	71	2	1
SC-II	2	0	0	0	91	TR	2	4	5	3
SC-III	TR	0	0	3	76	TR	1	13	1	17
SC-IV	7	0	0	0	66	TR	17	2	1	11
SW-III	0	0	0	2	77	1	TR	6	1	16
TS-IV	53	TR	0	0	4	16	11	24	2	15
TS-VI	21	0	0	0	4	1	1	9	6	55
TC-IV	69	0	0	0	0	2	TR	TR	TR	29
TC-VI	51	0	0	0	2	0	1	TR	1	37
SBM-V	24	3	0	0	TR	22	1	12	57	11
HS-IV	82	0	0	0	21	TR	11	3	4	17

<sup>a/</sup> CW=cottonwood-willow, SC=saltcedar, SW=seepwillow, TS=thorny shrub, TC=thorny shrub in canyons, SBM=screwbean mesquite, HS=western honey mesquite.

All workers have concluded that the cottonwood-willow, honey mesquite, and screwbean-mesquite communities are of major or even critical importance to many bird species, which is strongly reflected by the selection by birds of these habitats. Even though cottonwood (or screwbean) may make up a very small part of the total, they contribute greatly to height and foliage diversity and to patchiness that is important to many birds. However, the cottonwood-willow community is also quite diverse in species composition, which also contributes to bird species diversity and density. It is also

notable that the saltcedar communities contain very little of any other type of plant.

In the summer (May through July), cottonwood-willow and screwbean mesquite were the most preferred by the 28 species of birds analyzed (Table 12). Saltcedar had the highest density of birds because of a large number of white-winged doves.

During the winter (December-February), cottonwood-willow was preferred far more than any other community among 21 species of birds analyzed; 12 species strongly preferred it and none strongly preferred saltcedar (Table 12) (Engle-Wilson and Ohmart 1978a). Bird species with a narrow habitat breadth usually were not found in saltcedar (the white-winged dove was the only exception). Part of the attraction to cottonwood-willow was the denser and more diverse understory.

They observed that during January, February and March, bird densities were far greater in a previously rectified area where saltcedar was cleared 10-11 months earlier (175 per 100 acres) than in areas recently cleared or that remained in saltcedar (63 per 100 acres). They concluded, surprisingly, that rectification would reduce bird densities by 93% and 14 species would be lost during the breeding season, mostly by loss of nesting habitat for whitewinged and mourning doves, but many common passerines would also be displaced. During the winter, bird density would increase by 83% and only two species would be lost.

Along 163 miles of the Middle Rio Grande from Espanola to San Acacia, Hink and Ohmart (1984) made a detailed study of bird densities and species richness in relation to plant community-structural types. The saltcedar C-S types supported a distinct assemblage of summer resident species. The two most common were the mourning dove and the blue grosbeak which were common

Table 12. Habitat breadths of birds in the Rio Grande Valley, NM (from Engle-Wilson and Ohmart 1978a, his tables 7 and 8).

	Habitat preference <sup>a/</sup>		
	No. spp with pref. >28% (preferred)	No. spp with pref. >43% (strong pref.)	Mean % preference of all spp.
-----Summer (May-Jul.)-----			
Cottonwood-willow	8	3	18.5
Saltcedar	2	1	13.1
Saltcedar wetland	3	0	14.1
Thorny shrubs	3	1	11.8
Thorny shrub (canyon)	4	0	12.7
Screwbean mesquite	9	3	19.7
Disturbed areas	4	0	10.1
-----Winter (Dec.-Feb.)-----			
Cottonwood-willow	15	12	49.7
Saltcedar	2	0	9.4
Saltcedar wetland	4	2	9.9
Thorny shrubs	1	0	6.4
Thorny shrub (canyon)	0	0	3.6
Screwbean mesquite	3	1	9.4
Disturbed areas	1	1	11.6

<sup>a/</sup> Based on % of population of each bird species in each plant community.

in many C-S types. However, the mockingbird, lark sparrow, western meadowlark, and black-throated sparrow, all common residents, rarely if ever occurred in other riparian habitats. In winter, saltcedar supported much the same avian community as the other forest and woodland C-S types except that western meadowlarks were more abundant in saltcedar. Their report contains much detailed information that has not been adequately reviewed for this report.

4. The Middle Pecos River Valley.--The relationships between birds and plant community/structural types on the Pecos River was substantially different from that on the Lower Colorado. Hildebrandt and Ohmart (1982) surveyed the Middle Pecos River Valley from Santa Rosa, New Mexico, to just north of Highway 67 near Girvin, Texas.

Historically, this area seemingly contained no substantial riparian woodland community. Groves of cottonwoods were mentioned in some early accounts that agree closely with present-day groves primarily at Bosque Grande, 25 mi northeast of Roswell, and at Bosque Redondo near Ft. Sumner, New Mexico.

Today, the area consists of saltcedar, saltgrass, alkali sacaton, and mesquite. The latter in this area grows mostly as shrubby mats 15-18 m diam and less than 1 m high, or occasionally as small trees. Hildebrandt and Ohmart (1982) describe two woodland riparian communities, cottonwood and saltcedar and 4 non-woodland communities, alkali sacaton grassland, western honey mesquite/four-winged saltbush scrubland, acacia/creosotebush desert, and a small mixed weeds community.

Of the total area of riparian woodland, 93% (1,250 ha) is now in saltcedar; 45% of this is in the McMillan Delta, another large amount is in the Bitter Lake National Wildlife Refuge, and the rest mostly in narrow fringes along the river. Only 87 ha was in the taller SC-III type. A total of 834 ha was in native woodland (cottonwood CW-I and CW-II). They divided this into 15 community structural types based on counts of trees (not the percent canopy cover used on the Lower Colorado) along 50 transect lines, each 1500 to 8000 ft long and 412 ft lateral to the midline. They prepared detailed vegetational community/structural type maps for the entire study area. Six structural types and 9 community types were defined (Table 13).

Table 13. Pecos River Valley community and structural types (from Hildebrandt and Ohmart 1982).

Type	Description
-----Structural-----	
I	Trees 12-18 m in height, with a substantial amount of foliage above 12 m.
II	Scattered trees above 9 m but lacking substantial foliage above 12 m.
III	Very few trees above 9 m, but having substantial foliage between 4.6 and 7.6 m.
IV	Little foliage volume above 4.6 m, dense between 1.5 and 4.6 m.
V	Little foliage volume above 3 m, generally rather sparse, often with open areas between trees or groups of trees.
VI	Variable in height of foliage. Usually little volume above 1.5 m. Includes all areas recently disturbed by plowing and burning and areas with very sparse vegetation.
-----Community-----	
CW	Cottonwood-dominated communities.
SC	Saltcedar-dominated communities.
HM	Honey mesquite (or western honey mesquite)-dominated communities. <sup>a/</sup>
GC	Cleared communities dominated by grasses.
OC	Cleared communities dominated by various annual and perennial weeds and shrubs.
CR	native communities dominated by creosote bush.
AT	Communities dominated by four-winged saltbush.
-----Special areas-----	
DC-strips	Uncleared strips of saltcedar approximately 15 to 20 m wide that were adjacent to and paralleled the Pecos River.
MS	A single transect sampling a heterogeneous collection of plant communities with a canal supporting cattails and phragmites combined with influences of cottonwoods and saltcedar trees north and east of Loving, NM.

<sup>a/</sup> Mesquite in this area is mixed honey mesquite (*Prosopis glandulosa glandulosa*), western honey mesquite (*P. g. torreyana*) and gradtions between these two. Hildebrandt and Ohmart did not distinguish between the two subspecies.

Muddy Pecos River

119

However, the 15 C/S types used as the basis for the bird surveys were of very mixed species composition compared to the relatively species-pure C/S types of the Lower Colorado (Table 14).

Table 14. Mean tree and shrub counts (number per 0.23 ha) for each community structural type (from Hildebrandt and Ohmart 1982).

C/S type <sup>b/</sup>	Species and size class <sup>a/</sup>									
	CW <3 m	CW >3 m	SC >3 m	SC <3 m	HM	AT	Bac	Sal	Sua	Lar
CW-I		3.78	7.8	33.6	0.8	0.0				
CW-II	1.0	9.1	10.6	133.6	3.8	0.0	18.1	0.0		
SC-III			177.9	34.2		1.5				
SC-IV			126.9	59.6	0.3	1.8	14.1	0.1		0.6
SC-V		21.7	62.7	10.8	21.6	0.7	14.5	18.6		2.4
SC-VI		2.6	122.2			0.2				
DC-strips		139.5	19.3	0.2	0.7	1.4				9.5
OC-V		3.1	3.2	3.9	133.5	0.1	25.9	7.9		0.9
OC-VI		0.7	6.2	6.2	33.2	35.0	0.3		0.0	75.9
HM-V				98.2	93.0				5.9	0.1
HM-VI				75.6	30.7		0.3		7.3	16.2
GC-VI			0.3	3.8		3.5	1.7			8.2
CR-VI				30.2					208.8	10.4
AT-VI			0.1		109.2					

MS 0.12% 1.8 17.1 0.6 70.1 4.2 2.5 2.17 1.2 9.9 3.2

Tot a/ CW=Populus wislizenii, SC=Tamarix chinensis, HM=Prosopis glandulosa, AT=Atriplex canescens, Bac=Baccharis salicina, Sal=Salsola iberica, Sua=Suaeda spp., Larrea divaricata ssp. tridentata.

b/ See Table 8 for definitions.

Birds were censused 2 or 3 times each month for 21 months along the 50 transects, from September 1979 through May 1981. The greatest density of birds (29% of the 339,785 annual total) were present in the fall, 22% in the winter, 17% in the spring, 20% in early summer, and 12% in late summer. Granivores (other than game birds) made up 50.0% of the total and were

present mostly in the fall and winter. Game birds were 15.1% of the total and were most abundant during the spring and early summer. Bark and ground feeding insectivores were 18.4% of the total and were of relatively uniform abundance throughout the year. Foliage and aerial insectivores made up 14.1% of the total and were most abundant in early and late summer (Hildebrandt and Ohmart 1982).

They identified 91 species of birds during the study; 33.8% of the total numbers were one species, the white-crowned sparrow, a fall and winter granivore. <sup>u</sup> Morning doves accounted for 13.0% and dark-eyed juncos 10.9% of the total. <sup>^</sup> These three species together with 7 other species, each with 5.4 to 1.7% of the total (mockingbird, Bewick's wren, blue grosbeak, rufous-sided towhee, brown-headed cowbird, ruby-crowned kinglet, and northern oriole), accounted for 80.% of all birds counted.

Forty-seven species (nearly half of all species seen) each had less than 340 individuals (0.01% of the total). They assigned a rank for overall value to birds of each C/S type for each of the 5 annual seasons and for the year. ... In this composite score, bird density and number of species were given equal weight. Rankings were as follows (lower scores = greater value for birds):

<u>C/S type</u>	<u>Score</u>	<u>Rank</u>
MS	21.0	1
DC-strips	25.0	2
SC-IV	32.0	3
CW-II	43.5	4
SC-V	47.0	5
OC-V/VI	49.0	6
HM-VI	65.5	7
GC-VI	77.0	8

During the summer, the greatest densities of birds were in cottonwood, many of them mourning doves in early summer and grackles in late summer. In the fall and winter, the greatest densities were in saltcedar VI, Atriplex VI, DC strips, and cleared areas with weeds and shrubs (OC-V/VI); 92% of the birds in saltcedar VI, 67% of those in AT-VI, 59% of those in OC-V/VI, and 35% of those in the DC strips were white-crowned sparrows.

The "Miscellaneous" C/S type ranked first in overall value for birds. It had the greatest number of species in every season (Table 15) and ranked 2nd in later summer densities and moderate in densities in other seasons (Table 16). This type contained the greatest diversity of community elements, including open water, shoreline and emergent vegetation which probably attracted many species.

The DC-strips ranked 2nd in overall value for birds. They had the 2nd highest number of species and ranked 2nd in fall and 3rd in winter densities but ranked lower in summer breeding densities. They had high numbers of winter visitors, many of which used it for cover but fed in adjacent cleared areas. Transients were also somewhat higher here and these strips probably serve as corridors of travel for many species. The C/S maps of the entire Middle Pecos River prepared by Hildebrandt and Ohmart (1982) and their definition of this type show it to be saltcedar; however, their counts of trees in the transects surveyed show 139.5 cottonwood, 19.5 saltcedar, and 9.5 creosotebush per 0.23 ha.

The cottonwood-II community had the highest density of breeding birds (Table 10) and was 3rd in number of breeding species (Table 16). It also had strong peaks of density of spring and fall visitors and of fall transients.

Table 15. Number of species of birds in 14 community/structural types of riparian vegetation by seasons, in the Middle Pecos River Valley, September 1979 to May 1981 (from Hildebrandt and Ohmart 1982, tables 8-21).<sup>a/</sup>

		Community/Structural type (No. spp.)										
Rank		Mar-May		Jun-Jul		Aug-Sept		Oct-Nov		Dec-Feb		
1	1	Misc	(36)	Misc	(30)	Misc	(32)	Misc	(31)	Misc	(32)	32.2
2	2	DC	(34)	DC	(28)	SC-IV	(29)	DC	(30)	DC	(31)	DC - 28.2
3	3	SC-IV	(29)	CW-II	(27)	SC-V	(24)	OC	(28)	OC	(27)	SC-IV - 25.6
4	4	CW-II	(28)	SC-IV	(27)	CW-I	(23)	SC-V	(24)	SC-IV	(22)	SC-V - 22.8
5	5	CW-I	(27)	SC-V	(23)	CW-II	(23)	SC-VI	(22)	SC-V	(17)	CW-I - 22.0
6	6	OC-V/VI	(27)	SC-III	(22)	SC-VI	(23)	HM-V	(22)	CW-II	(16)	OC - 22.3
7	7	SC-V	(26)	HM-VI	(20)	HM-VI	(21)	HM-VI	(21)	AT-VI	(15)	SC-VI - 22.1
8	8	HM-V	(24)	SC-VI	(20)	DC	(18)	SC-IV	(21)	HM-VI	(15)	CW-I - 19.8
9	9	SC-VI	(22)	CW-I	(19)	SC-III	(17)	CW-II	(16)	SC-VI	(14)	HM-VI - 19.1
10	10	HM-VI	(20)	OC-V/VI	(14)	OC	(15)	AT-VI	(16)	CW-I	(13)	
11	11	AT-VI	(19)	HM-V	(10)	AT-VI	(14)	SC-III	(15)	HM-V	(12)	
12	12	GC-VI	(19)	HM-VI	(10)	GC-VI	(13)	CW-I	(14)	SC-III	(12)	
13	13	SC-III	(17)	CR-VI	(10)	HM-V	(12)	CR-VI	(13)	CR-VI	(10)	
14	14	CR-VI	(16)	AT-VI	(6)	CR-VI	(9)	GC-6	(11)	GC-VI	(9)	

<sup>a/</sup> See Table 8 for definition of community/structural types.

this table is  
not done  
yet

SC-6 = some pine SC / 3m  
SC-3 = " " " + 20% < 3m  
SC-4 = much CW + some other a little HM  
SC-5 = very mixed - SC, CW, HM, some, some

123

Table 16. Density of birds in 14 community/structural types in the Middle Pecos River riparian area by seasons, September 1979 to May 1981 (compiled from Hildebrandt and Ohmart 1982).<sup>a/</sup>

Overall Rank	Community/Structural type (No. spp.)					
	Rank	Mar-May	Jun-Jul	Aug-Sept	Oct-Nov	Dec-Feb
SC-VI - 2.81	1	AT-VI (365)	CW-I (449)	CW-I (386)	SC-VI (982)	SC-VI (771)
DC - 4.22	2	SC-IV (243)	CW-II (368)	Misc (207)	DC (530)	AT-VI (416)
SC-IV - 4.43	3	SC-VI (224)	SC-IV (288)	SC-VI (161)	AT-VI (368)	DC (364)
Misc - 5.24	4	DC (213)	Misc (266)	SC-IV (158)	OC (310)	OC (355)
CW-I - 5.45	5	CW-II (197)	SC-III (210)	DC (142)	SC-IV (274)	Misc (203)
CW-II - 5.86	6	CW-I (195)	SC-VI (189)	SC-V (95)	SC-V (242)	CW-II (198)
AT-VI - 6.07	7	Misc (163)	DC (162)	CW-II (94)	SC-III (242)	SC-V (194)
SC-V - 7.14	8	SC-III (124)	SC-V (114)	HM-V (91)	Misc (192)	SC-IV (190)
SC-III - 8.29	9	OC-V/VI (116)	HM-V (68)	CR-VI (81)	CW-II (124)	CW-I (181)
OC - 8.610	10	SC-V (114)	HM-VI (68)	SC-III (81)	CW-I (110)	CR-VI (124)
HM-V - 10.11	11	HM-V (99)	CR-VI (67)	AT-VI (77)	HM-V (98)	SC-III (82)
CR-VI - 10.812	12	CR-VI (84)	OC-V/VI (30)	HM-VI (56)	CR-VI (89)	GC-VI (61)
HM-VI - 12.613	13	GC-6 (50)	AT-VI (29)	GC-VI (36)	HM-VI (69)	HM-V (42)
GC-VI - 13.214	14	HM-VI (40)	GC-6 (26)	OC-V/VI (35)	GC-VI (60)	HM-VI (37)

<sup>a/</sup> See Table 13 for definition of community/structural types.

pg 118

The relatively mature saltcedar-IV communities ranked 3rd in overall value for birds. Both number of species and density were consistently high except in winter. The younger saltcedar V and VI communities ranked lower. Number of species present was moderate in summer and fall but lower in other seasons. SC-VI ranked 1st in density in both fall and winter (92% white-crowned sparrows). These birds probably use saltcedar for shelter and feed on seeds in the nearby "Other Cleared" (OC-V/VI) habitats. Both SC-IV and SC-V types contained more cottonwood and other trees than saltcedar, although SC-VI was nearly all saltcedar. The abundance of annual vegetation

in saltcedar communities (and the large seed crop produced by annuals) is much greater on the Pecos than on the Colorado, which Hildebrandt and Ohmart (1982) ascribe to higher rainfall and lower soil salinity along the Pecos.

Saltcedar III (mostly 15-25 ft tall) would be expected to be the most attractive saltcedar structured type, as it was on other rivers. These transects, however, were the most purely monospecific, with no cottonwood, 1.5 shrubs of four-winged saltbush, and 6.3 miscellaneous trees, compared with 212.1 trees of saltcedar per 0.23 ha. In bird density, SC-III ranked 5th in early summer, 7th in fall, 8th in spring, 10th in late summer, and 11th in winter (Table 16). In bird species diversity, SC-III ranked 6th in early summer, 8th in late summer, and 11th to 13th in other seasons (Table 15).

Mesquite ranked only 6th to 13th in number of bird species and only 8th to last in bird density on the Pecos, while western mesquite on the Lower Colorado and in other studies ranked near the top.

A casual examination of the data presented by Hildebrandt and Ohmart (1982) would lead to the conclusion that birds use saltcedar on the Pecos River to a considerable extent and much more than they do on the Lower Colorado River. Birds clearly are more abundant and have greater species diversity in the sampled areas on the Pecos. Saltcedar IV and V ranked 3rd and 5th in combined species richness-density, exceeded only by "Miscellaneous" and "DC-strips," with cottonwood II ranked 4th. During the fall and winter, SC-VI had by far the greater bird densities than any other S/C types.

However, a closer examination of the vegetative composition of the saltcedar transects selected for sampling reveals that they have a considerably greater plant diversity than those of the Colorado River. SC-IV contained twice as many cottonwood trees as saltcedar trees and SC-V

contained as much cottonwood, mesquite and baccharis combined as saltcedar. Saltcedar VI was relatively pure but even this contained 2% as many cottonwood trees over 10 ft tall as saltcedar. Saltcedar III was also relatively pure but also contained a small amount of four-winged saltbush and a 3% composition of miscellaneous shrubs. However, SC-III ranked quite low in value to birds although it should have been the most attractive saltcedar type because it is taller and more mature. Also, Hildebrandt and Ohmart (1982) commented that annual plants were much more abundant in saltcedar on the Pecos than on the Colorado, which they attributed to higher rainfall and lower soil salinity on the Pecos. Hunter et al. (1985) speculated that the lower air temperature in the Pecos River Valley might make conditions in saltcedar thickets more favorable for birds (the Pecos is at an elevation 3000 to 4000 ft higher than the Lower Colorado).

*therefore  
different  
Insects* The most reasonable conclusion to draw from the data presented by Hildebrandt and Ohmart (1982) is that birds use saltcedar communities more on the Pecos River because these saltcedar communities have a more diverse vegetative composition and also that they are cooler, than communities on the Colorado and not that saltcedar itself is more attractive. Differences in the bird species represented also may influence the apparent differences in usage. For example, on the Pecos, huge numbers of white-crowned sparrows apparently use saltcedar only for cover in the fall and winter and feed in nearby areas of annual plants. Without this species, SC-VI would rank very low in fall and winter, rather than its actual #1 rank, and the other saltcedar types would also rank lower.

5. Sonora, Mexico. Near Hermosillo, Sonora, Scudday (Appendix III, this report) observed birds in an area of saltcedar (mostly less than 15 ft tall) that included scattered native trees and shrubs. White-winged doves,

mourning doves, ground doves, great-tailed grackles, phainopepla, and lesser nighthawks were common; and 6 other bird species were rare.

6. Comparisons of Different River Valleys.--Engle-Wilson (1981) compared two community types, each in two locations in Arizona--velvet mesquite on the Colorado and Verde Rivers and saltcedar on the Colorado and Gila Rivers--as foliage-height diversity increased:

	<u>No. bird species</u>	<u>Bird density</u>
Colorado	decreased	decreased
Gila	increased	increased

Average density of birds in the two community types (his Table 10) indicated that only the white-winged dove preferred saltcedar and all other birds preferred velvet mesquite:

	<u>Number birds per 0.4 ha</u>	
	<u>Mesquite</u>	<u>Saltcedar</u>
Gambel's quail	4.50	0.98
White-winged dove	0.68	3.80
Mourning dove	8.76	3.85
All birds (total)	23.3	16.6

When usage of plant communities by birds was compared on 3 different rivers (the lower Colorado, middle Rio Grande and middle Pecos) by Hunter et al. (1985), 12 of the 19 bird species studied clearly preferred cottonwood-willow, 12 preferred western honey (or honey) mesquite and 4 preferred saltcedar on at least one river (Table 17). However, the tree species preferred differed on each river; cottonwood-willow was preferred on the Colorado, honey mesquite on the Rio Grande, and little preference was shown on the Pecos. Mid-summer migrants strongly preferred cottonwood-willow and avoided saltcedar on the Colorado. Resident species preferred honey mesquite and avoided saltcedar on the Rio Grande. They speculated that temperatures might influence the choice of habitat in the different areas: saltcedar might not mitigate high temperatures as well as would other community types.

Table 17. Numbers of bird species showing clear preference and mean population of all birds per unit area for different plant communities on three western rivers (from Hunter et al. 1985).

River	Number bird species (mean population) <sup>a/</sup>			
	CW	SC	HM	SB
Lower Colorado	6 (42.9)	0 (14.5)	1 (24.3)	0
Middle Pecos	5 (37.9)	4 (34.8)	3 (26.2)	-
Rio Grande (west TX)	1 (24.8)	0 (20.9)	8 (54.1)	-

<sup>a/</sup> CW=cottonwood-willow, SC=saltcedar, HM=honey mesquite, SB=screwbean mesquite.

*see summary on pg 390 for B*

## B. Terrestrial Vertebrates

1. Small Mammals.--Fewer southwestern mammals than birds appear to be strongly dependent on riparian areas. However, several species do show dependency (Hubbard 1977); these are the water shrew, Arizona grey squirrel, beaver, meadow vole, muskrat, raccoon, mink, and otter. Rodent populations have been studied intensively in only a few riparian areas. In the Lower Colorado River Valley, Anderson and Ohmart (1977b, 1984a) over a 63-month period from 1974-1979, trapped a total of 14,452 rodents of 13 species during 219,780 trap nights along 814 trap lines. Numbers of each species caught were:

Cactus mouse ( <u>Peromyscus eremicus</u> )	8,558
Desert pocket mouse ( <u>Perognathus penicillatus</u> )	1,782
Merriam's kangaroo rat ( <u>Dipodomys merriami</u> )	1,406
Deer mouse ( <u>Peromyscus maniculatus</u> )	1,275
White-throated wood rat ( <u>Neotoma albigula</u> )	1,039
Southern grasshopper mouse	119
Western harvest mouse	70
Desert kangaroo rat	65
House mouse	22
Hispid cotton rat	6

*om*

Most of these rodent species showed some preference for certain vegetation types, for example, the cactus mouse for saltcedar, the white-throated wood rat, desert pocket mouse, desert kangaroo rat and Merriam's kangaroo rat for ~~veget~~<sup>honey</sup> mesquite and screwbean mesquite, and the deer mouse seemed to avoid mesquite (Table 18). Areas with bare soil attracted the Merriam's kangaroo rat and the desert pocket mouse, and sandy areas attracted the desert kangaroo rat. However, none showed strong preferences and all were found in several vegetation types. The cactus mouse probably would not attain maximum densities but fair numbers would be attracted to other vegetation types. Anderson and Ohmart (1984a) concluded that the best management system for all species would be to create an area that is horizontally diverse.

On the Rio Grande of western Texas, ~~rodent-habitat-preference appears to be much different.~~ In 20,250 trap nights Engle-Wilson and Ohmart (1978a) caught 614 rodents of 14 species from April to November 1977. Of the seven vegetation types sampled, saltcedar wetland was 5th in density and last in number species and saltcedar was 6th in density and 5th in number of species (Table 19).

Along the Rio Grande in Big Bend National park, 30 species of terrestrial mammals occur. Boer and Schmidly (1977) made the first survey of mammals in the riparian area per se. They trapped 1292 rodents in 12,960 trap nights (720 trap nights in each of 18 sites), capturing the following species:

<u>Rodent species</u>	<u>No. trapped</u>
Desert pocket mouse	896
White-footed mouse	162
Southern plains wood rat	73
Hispid cotton rat	70
Merriam's kangaroo rat	65
Cactus mouse	19
Silky pocket mouse	5
Nelson's pocket mouse	2

Table 18. Habitat preference of rodents in the Lower Colorado River Valley, 1974-1979 (Anderson and Ohmart 1984a).

Rodent species (warm or cool season)	Tot. no. caught	Mean no. per 270 trap nights <sup>a/</sup>					
		SC	SC-WHM	SB	CW	WHM	AW
Cactus mouse (warm)	{8,558	17.2	18.1	7.5	12.6	6.7	6.6
Cactus mouse (cool)		17.8	16.6	13.5	11.8	8.7	6.6
Desert pocket mouse (warm)	{1,782	3.2	3.3	2.6	1.6	3.8	4.6
Desert pocket mouse (cool)		.63	.78	.90	.38	.90	.20
Merriam's kangaroo rat	1,406	1.72	.34	2.52	.37	2.11	1.87
Deer mouse <sup>b/</sup>	1,275	2.67		1.60	1.86	.60	
White-throated wood rat (warm)	{1,039	1.04	.42	1.94	1.85	1.42	.38
White-throated wood rat (cool)		1.09	1.00	1.39	1.32	1.41	.30
Southern grasshopper mouse	119	.13	--	.90	.12	.09	.03
Western harvest mouse	70	.03	.06	.01	.29	.03	.12
Desert kangaroo rat	65	.072	0	.077	0	.178	.10
		45.582	40.6	32.94	32.19	25.94	20.8

a/ SC=saltcedar, SC-WHM=saltcedar-western honey mesquite, SB=screwbean mesquite, CW=cottonwood-willow, WHM=velvet mesquite, AW=arrowweed.

b/ From Anderson and Ohmart (1977b); values cannot be compared with other rodent species but are valid across vegetation types.

45,582 SC  
152,47 other

Table 19. Habitat preference for rodents in the Rio Grande Valley of western Texas (from Engle-Wilson and Ohmart 1978a).

Plant community	Number per 270 trap nights		Number species		Diversity
	Summer	Winter	Summer	Winter	
Pediment	14.1	4.0	18.1	7 2 9	0.52
Thorny shrub	10.3	7.2	17.5	9 8 17	1.44
Screwbean-wolfberry	9.6	8.5	18.1	6 5 11	1.36
Saltcedar wetland	8.5	1.0	9.5	4 1 5	1.05
Cottonwood-willow	6.6	8.0	14.6	6 5 11	1.66
Saltcedar	6.3	2.4	8.7	4 3 7	0.99
Thorny shrub-canyons	2.8	4.0	6.8	5 1 6	1.52

They did not summarize their data by plant species types. However, they found that vegetation changes during the past 30 years had resulted in the elimination of Ord's kangaroo rat and the increased abundance and distribution of the hispid cotton rat and the white-footed mouse. The rodent fauna in the riparian area had lower evenness, richness and diversity indices than did desert-shrub, grassland or woodland.

→ The population of beavers (which in that area eat cane, seepwillow, willow and cottonwood) had decreased greatly because their food plants were decreasing; there was no evidence that beavers ate saltcedar, (Boer and Schmidly 1977). <sup>further west</sup> Engle-Wilson and Ohmart (1978a) found two beaver dams on the Rio Grande, one among willow and cottonwood and the other in nearly pure saltcedar. (2)

On the Middle Rio Grande, Hink and Ohmart (1984) reported that in capture rate of small mammals, saltcedar SC-IV ranked 9th, SC-VI ranked 15th and SC-V ranked 16th among 25 community-structural types sampled; several cottonwood-willow CS types, marsh, drain, and a wet area all ranked higher, some with more than twice the catches as in saltcedar. They gave a detailed description of the habitat association of the 17 species of small mammals they captured. (1)

2. Reptiles and Amphibians.--Riparian areas are, of course, essential for amphibians (frogs, toads and salamanders) whose immature stages must develop in water. These systems are also critical or are preferred by many species of reptiles (Hubbard 1977). In the Grand Canyon, Warren and Schwalbe (1985) compared densities of 5 lizard species in 10 different habitat types (Table 20). Dense saltcedar ranked next to last and open saltcedar ranked 3rd out of the 10 habitats in numbers of lizards trapped. They also gave densities of four of these lizard species from studies by other workers in

Table 20. Lizard densities along the Colorado River in Grand Canyon, summer 1984 (Warren and Schwalbe 1985).

Habitat	Number/ha (mean of June and August)					
	Side blotched	Western whiptail	Desert spiny	Tree	Black collared	All lizards
<u>Shoreline</u>						
Rocky shore	34	11.5	30	60	0	135
Cobble bar	64	29	14	0	1.5	107.5
Cliff face	0	0	0	540.5	0	540.5
<u>River riparian</u>						
New zone						
Open <u>Tamarix</u>	53	69	57.5	6.5	0	184
Arrowweed	34	26.5	11.5	0	0	70.5
Dense <u>Tamarix</u> <sup>a/</sup>	0	13	40	0	0	53
Old zone						
Terrace	15	15	14	14	1.5	51.5
Talus <sup>a/</sup>	28	10	15	0	0	53
<u>Non-river</u>						
Desertscrub	11.5	6.5	2.5	0	3.5	22.5
Riparian	<u>116.5</u>	<u>0</u>	<u>62.5</u>	<u>75</u>	<u>0</u>	<u>254.0</u>
<u>Grand mean</u>	32.5	19	18	16.5	0.85	86.5

<sup>a/</sup> Collections made only in June; for most lizards, densities were greater in June than in August.

the Southwest in various habitat types. Jones and Glinski (1985) on the Hassayampa River near Wickenburg, AZ, found that 7 lizard species were most attracted to debris heaps and leaf litter among 26 habitat variable examined, and some species were attracted to rocks. They did not make associations with vegetation types.

Jakle and Gatz (1985) compared catches of lizards, snakes and frogs in four vegetation types near Florence, AZ, from late March to early May during 406 trap days. They caught 104 individuals in the following habitats:

	<u>Number/100</u> <u>trap nights</u>
Mature saltcedar (riparian)	6.25
Mature mesquite (riparian)	21.70
Desert upland	30.95
Desert wash	30.95

On the Rio Grande of western Texas, Engle-Wilson and Ohmart (1978a) found almost no reptiles in saltcedar; 33 were trapped in thornscrub and none in saltcedar, while a total of 30 were sighted but only 3 in saltcedar. They found most toads in saltcedar and thornscrub.

On the Middle Rio Grande, Hink and Ohmart (1984) captured 18 species of reptiles and amphibians in pitfall traps in 17 different plant community-structural types. Three species were common and widespread--the eastern fence lizard, the New Mexico whiptail and the woodhouse toad. Overall capture rate was greater the more open the vegetation in a habitat. One of the three saltcedar transects ranked equal to cottonwood-willow and a drainage area but the other two ranked lower. They gave a detailed discussion of the habitat associations of the various species captured.

C. Damage Caused by Saltcedar to Non-consumptive Wildlife Use ("Bird Watching" etc.)

Each 5 years since 1955, the Fish and Wildlife Service-USDI has conducted a national survey of fishing, hunting and wildlife associated with recreation; the 1985 survey was the first to gather information about persons who observe, photograph or feed wildlife. In the 1985 survey, 111,000 households were screened by telephone and detailed questionnaires were then mailed; 28,011 fishermen and hunters and 26,671 non-consumptive participants completed the questionnaires (FWS-USDI 1988). The data were not summarized in such detail that a comparison can be made of hunters vs. "bird watchers" that utilize riparian areas in the Southwest so that the impact of saltcedar

invasion on these activities could be evaluated. However, estimates can be made from the summaries by making certain assumptions (Table 21).

All the various items purchased for consumptive use of wildlife (fresh-water fishing exclusive of the Great Lakes, and for big game, small game and migratory bird hunting) totaled \$26.7 billion and for non-consumptive use (observing, photographing and feeding) totaled \$14.3 billion (53.5% of consumptive expenditures) in the entire U.S. during 1985 (Table 22). Expenditures for non-consumptive usage were not given by state, but consumptive expenditures were \$460.9 million in Arizona and \$246.6 million in New Mexico (Table 23). We assumed that the consumptive:non-consumptive ratio is the same in Arizona and New Mexico as the national ratio, giving \$246.6 million in Arizona and \$131.9 million in New Mexico for non-consumptive usage (Table 21).

However, a substantial amount of non-consumptive usage is residential (within 1 mile of the residence of the participant) (Table 24) which would be little affected by conditions in riparian areas since few residences are located there. The eight-state Mountain Area (Fish and Wildlife Service 1988) reported 2,119,000 non-resident primary and 6,081,000 non-resident secondary participants, while resident participants totaled 5,668,000 primary and 6,835,000 secondary (Table 24). Giving double weight to the primary participants (assuming they spent twice as much as secondary on certain items) gave an estimation of 36.2% spent by non-residential and 63.8% by residential in certain items used by both (Table 25). We assumed that other items were used exclusively by either residential or non-residential. Summing all non-consumptive expenditures for various items so prorated gave a total of 79.36% by non-residential and 20.64% by residential participants (Table 18). We assumed that these ratios were the same for Arizona and New Mexico as for the eight mountain states (Table 21).

Table 21. Calculation of the value of non-consumptive use of wildlife (observing, feeding, photographing) in riparian areas.

Category <sup>a/</sup>	Expenditures X\$1000		
	Ariz.	New Mex.	U.S.
A) Total consumptive use (hunting & fishing) (Table 1)			\$26,667,663
Total non-consumptive (observe, photo, feed)			14,267,213
% non-consumptive of consumptive use			53.50%
B) Total expenditure for hunting and fresh- water fishing (not Great Lakes) (Table 2)	\$460,876	\$246,630	27,854,813
C) Non-consumptive use = State totals (B) X 53.5% =	246,569	131,947	
D) Primary non-residential proportion (C) X 79.36% (from Table 4)	195,667	104,713	
E) Proportion of non-consumptive usage in riparian areas = (D) X 80%	156,541	83,770	
F) Proportion of riparian area occupied by saltcedar = 56.91% (Table 6) (E) X 56.91%	89,087	47,674	
G) Loss to birds caused by saltcedar (Table 5) (F) X 33.18%	29,559	15,189	

<sup>a/</sup>Table numbers in parenthesis indicate table number from Fish and Wildlife Service (1988).

Table 22. Expenditures for fishing, hunting and non-consumptive usage of wildlife in the U.S., 1985 (from Fish and Wildlife Service 1988).

	Fresh water fishing (22) <sup>a/</sup>	Big game (26)	Small game (27)	Migratory bird (28)	Non- consumptive (66)
<u>Trip related</u>					
Food	3,182,982	929,063	387,309	233,713	1,762,982
Lodging	695,533	178,594	43,919	37,851	750,297
Public transport	114,277	49,281	19,911	9,895	330,264
Private transport	2,613,091	763,858	433,008	207,467	1,357,424
Guide & pack fees	79,267	78,432	13,853	19,551	106,103
Land use fees	120,288	46,937	22,609	16,577	73,411
Boat costs	855,398	--	--	--	--
TOTAL	7,660,836	2,046,165	920,609	525,054	4,381,487
<u>Equipment &amp; supplies</u>					
Major (guns, fishing poles, cameras, binoculars, etc.)	960,602	964,729	293,801	118,999	1,088,931
Minor equipment	176,492	103,315	33,790	48,116	239,413
Supplies (ammo, bait, film, bird seed, etc.)	1,569,769	142,200	116,696	62,046	1,117,711
Dogs	--	69,732	110,498	32,626	--
Other	68,743	28,881	5,178	4,482	96,784
TOTAL	2,775,606	1,308,857	559,963	266,269	2,542,317
<u>Auxiliary equipment</u>					
Camping equipment	126,487	32,357	3,438	1,033	408,315
Special clothing, boots, etc.	145,213	273,772	53,110	49,748	310,043
Other	5,798	2,249	--	--	--
Special equipment	5,965,300	1,128,741	130,448	79,503	5,233,792
<u>Other</u>					
Magazines	46,118	14,405	4,032	1,229	230,114
Dues & contributions	19,687	10,334	3,105	16,232	250,211
Licenses	325,314	299,957	61,821	63,041	--
Taxidermy	19,767	95,225	3,629	6,372	--
Land leases	705,300	755,389	73,264	80,445	--
GRAND TOTAL	17,795,427	5,967,449	1,815,216	1,089,571	14,267,263
		-----26,667,663-----			

<sup>a/</sup> Parenthetical numbers below column headings denote table number from Fish and Wildlife Service 1988).

able 23. Consumptive usage (hunting and fishing): number of participants, days of activity, and expenditures in 1985 (from Fish and Wildlife Service 1988) (values X1,000).

Activity <sup>a/</sup>	Hunting <sup>a/</sup>			Fresh water fishing		Expendi- tures Total \$ (18,89)b/
	Big game	Migratory birds	Small game	Total	% of U.S. Great Lakes)	
<b>RIZONA</b>						
Participants (16 yrs & older)(77,82)	188	92	137	259	(1.55)	638
Participants (6-15 yrs old)(74)						117
Days of activity (87,85)	1,284	562	1,447	3,434	(1.03)	7,800
Expenditures (91,90,89) \$				119,943	(1.19)	310,217
<b>NEW MEXICO</b>						460,876
Participants (16 yrs & older)(77,82)	126	28	49	150	(0.90)	413
Participants (6-15 yrs old)(74)						54
Days of activity (87,85)	582	237	430	1,387	(0.42)	4,772
Expenditures (91,90,89) \$				66,874	(0.66)	170,823
<b>TEXAS</b>						246,630
Participants (16 yrs & older)(77,82)	1,131	691	715	1,488		2,479
Participants (6-15 yrs old)(74)						693
Days of activity (87,85)	10,923	4,871	8,506	24,106		54,278
Expenditures (91,90,89) \$				1,074,600		2,051,914
<b>I.S.</b>						3,403,841
Participants (16 yrs & older)(77,82)	12,520	5,036	10,831	16,684		38,433
Participants (6-15 yrs old)(74)						10,760
Days of activity (87,85)	131,330	41,682	132,263	334,013		976,564
Expenditures (91,90,89,18) \$	5,967,449	1,089,571	1,815,216	10,059,386		17,795,427
						27,854,810

<sup>1/</sup> Other animals (\$355,607 for U.S.) not included.

<sup>2/</sup> Parenthetical numbers following column headings and categories denote table number from Fish and Wildlife Service 1988).

Table 24. Non-consumptive usage of wildlife (observing, photographing, feeding): number of participants and expenditures for 1985 (from Fish and Wildlife Service 1988) (values x1000).

	Number of Participants				Total	\$ Expendi- tures (89) <sup>a/</sup>
	Primary		Secondary			
	Non- resident	Resident	Non- resident	Resident		
<u>8-State Mountain Area (excluding Texas):</u>						
Observing (67,68) <sup>a/</sup>	2,102	3,577				
Photographing (67,68)	1,198	1,111				
Feeding (67,68)	<u>744</u>	<u>3,961</u>				
TOTAL (67,68,70)	?	<u>5,668</u>	<u>6,081</u>	<u>6,835</u>		
	6,099			7,634		
<u>State totals</u>						
Arizona, 16+ yrs old (78,89)	441	1,383	1,384	1,629	1,933	329,328
6-15 yrs old (79)	93	207	280	308	363	
New Mexico, 16+ yrs (78,89)	189	605	594	769	848	115,504
6-15 yrs (79)	38	76	139	143	176	
Texas, 16+ yrs (78,89)	1,433	5,815	5,630	6,959	8,352	1,403,511
6-15 yrs (79)	410	1,047	1,336	1,568	1,943	
U.S., 16+ yrs (78,89)	29,347	105,286	89,532	117,411	134,697	14,267,213
6-15 yrs (79)	6,615	16,151	18,208	21,844	26,264	

<sup>a/</sup> Parenthetical numbers following column headings and categories denote table number from Fish and Wildlife Service 1988).

Table 25. Allocation of primary non-consumptive usage of wildlife to non-residential or residential usage (from Fish and Wildlife Service 1988, various tables).<sup>a/</sup>

Item	Total expenditures (X \$1000)	Non-residential (X \$1000)	Residential (X \$1000)
Participants (8 mountain states):			
Primary (X2)(67,68) <sup>b/</sup>		2,119	5,668
Secondary (70)		6,081	6,835
Allocations		36.2%	63.8%
Expenditures in U.S. (66)			
All trip related	4,430,808	4,430,800	0
All camping equipment	506,861	506,861	0
All special equipment	5,233,751	5,233,751	0
Equipment and supplies:			
Bird seed	1,117,186	0	1,117,186
Nest boxes, houses, baths, etc.	239,421	0	239,421
Packs, cases, etc.	211,728	211,728	0
Cameras, binoculars, etc.	1,950,299	706,008	1,224,291
Magazines, dues, etc.	480,317	173,875	306,442
Other	96,788	35,037	61,751
TOTAL		11,298,122	2,938,091
% OF TOTAL		79.36%	20.64%

<sup>a/</sup> Allocation of expenditures based on the assumption that all trip related, camping and special equipment (travel trailers, off-road vehicles, pickups, etc.) are for non-residential use; all feeders, baths, etc., and bird seed are for residential use; allocation of other items was based on the average percent of non-residential and residential participants in the 9 mountain states, giving double weight to primary uses and single weight to secondary users.

<sup>b/</sup> Parenthetical numbers following column headings and categories denote table number from Fish and Wildlife Service 1988).

In the semi-arid Southwest, ~~riparian areas are by far the most~~ important habitats for birds and many other animals. We estimated that 80% of the non-residential consumptive usage occurs in riparian areas, although we could find no data on this point (Table 21). (Dr. Steve Russell, Dept. Ecology and Evolutionary Biology, Univ. Ariz., Tucson, agrees with this percentage. Pers. commu. 13 April 1989).

To then calculate the losses caused by saltcedar, the proportion infested by saltcedar and the detrimental effect on non-consumptive usage must be known. On the Lower Colorado River, Anderson and Ohmart (1984b) measured the species composition on 111,691.8 acres of riparian vegetation; 63,568 acres (56.91%) was occupied by saltcedar. Younker and Anderson (1986), also on the Lower Colorado River, measured 107,649 acres of vegetation, of which 41.8% (Table 2) (or 56.8% as calculated in Table 1) was saltcedar, mostly Types IV and V. On the lower Gila River, Haase (1972) reported that more than 50% of the 16,356 acres of floodplain vegetation was saltcedar.

Multiplying the primary non-consumptive expenditures for Arizona (\$195,667,000) by the proportion of this usage in riparian areas (80%), then by the proportion of riparian areas infested with saltcedar (56.9%), then by the reduction in value for birds caused by saltcedar (mean of density - number of species = 33.18%) (Table 14) gives a total loss of non-consumptive use caused by saltcedar of \$29,559,000 per year in Arizona (Table 21). Similar calculations for New Mexico have not yet been made, but if the various ratios are the same as for Arizona, the losses would total \$15,818,000 per year in New Mexico.

We did not calculate the value of the time of the participants spent in the various non-consumptive activities: this information could be extracted from the Fish and Wildlife Service (1988) report in a manner similar to that

used above for direct expenditures. Preliminary observation indicates that these values are approximately equal to the direct expenditures, which would double the annual losses caused by saltcedar to \$60 million in Arizona and \$33 million in new Mexico.

Losses in both Arizona and New Mexico may be somewhat less than these amounts because the extent of saltcedar infestation in other riparian systems may be less than the 50-57% rate in the two examples cited. In particular, saltcedar on the middle Rio Grande of New Mexico (163 river miles from Espanola north of Santa Fe to near Socorro) surveyed by Hink and Ohmart (1984) seems to occupy a relatively small part of the area. On the Rio Grande of western Texas, Engle-Wilson and Ohmart (1978a, his Table 1) reported that 40.0% of the 1610 acres sampled was in saltcedar. However, Hildebrandt and Ohmart (1982) reported that on the Pecos River from Santa Rosa, NM, to Girvin, TX, saltcedar occupies 27,788 acres (93% of the total) and native woodland occupies only 2,050 acres; before clearing, saltcedar probably occupied 74,000 acres. Only 215 acres was classified as SC-III that was large enough for good dove habitat.

We did not yet attempt to calculate non-consumptive losses caused by saltcedar in Texas. Such an estimate could be made from the data in Fish and Wildlife Service (1988) by apportioning the population, area, or miles of river in the western 40% of the state that is heavily infested. Texas has the highest non-consumptive usage of wildlife in the U.S. (Fish and Wildlife Service 1988), probably due both to the large area and high human population. Total expenditures in Texas were \$3.404 billion which was more than 7 times that of Arizona and nearly 14 times that of New Mexico (Table 23). Although only ca. 40% of the state is infested, and that in the area of lowest population, losses might still equal those of Arizona and New Mexico combined.

Non-consumptive wildlife use is an activity in which both men and women and all age groups actively take part. Nationwide, women outnumber men by 51 to 49% among non-residential and 54 to 46% among residential participants. Among non-residents, the peak of participation is with the 25-45 year age group, but the over-65 group is 6% of the total. Among residential participants, activity is almost uniform among all age groups, with the over-65 group making up 15% of the total (Fish and Wildlife Service 1988).

Brown (1989) in his economic analysis of the impacts of biological control of saltcedar, cautioned that the proportion of total birdwatchers that use saltcedar infested areas could be small because alternative habitats are available and are preferred. He estimated from the data of the Fish and Wildlife Service (1989a) that total trip-related expenditures for bird watching in Arizona were \$59.0 million annually, or \$23.12 per trip for 2,554,000 trips. The next step would be to determine how many trips were associated with bird watching in saltcedar habitats but no data exist for this. Expenditures could range from insignificant to several million dollars per year. The value of alternative vegetation would be the difference in the amount of additional expenditures that participants are willing to make as a result of increased species and numbers (Brown 1989).

#### D. Game Birds - The White-winged Dove

The white-winged dove (Zenaida asiatica) is one of the most popular of all game birds within its area of distribution which extends 100-300 miles into the southern United States from Mexico. It originally nested in native riparian vegetation; but in the many western areas, it heavily uses saltcedar since that plant has invaded and replaced much of the original vegetation. Since this new dependency of the white-winged dove on saltcedar is one of

the major conflicts of interest to a biological control program, the biology, habitat dependency and scope of the dove-hunting enterprise is examined here in considerable detail.

Essentially all available information on the white-winged dove was compiled into a book entitled "Whitewings" by Cottam and Trefethen (1968). I have, for the most part, assembled the information since that time, with mention of some key sources from the earlier work.

1. Taxonomy and Distribution.--The white-winged dove was described by Linneaus in 1758 as Columba asiatica because of erroneous information that the specimen was from Asia. The species occurs from Southern California and Arizona to southern Texas, throughout Mexico, the Greater Antilles, Central America, and the coastal area of Ecuador and Peru. Saunders (1968) recognized 12 subspecies, 4 of which occur in the United States and northern Mexico (Fig. 11); these are:

<u>Zenaida asiatica asiatica</u>	Eastern white-winged dove
<u>Z. a. monticola</u>	Mexican highland white-winged dove
<u>Z. a. grandis</u>	Upper Big Bend white-winged dove
<u>Z. a. mearnsi</u>	Western white-winged dove

The eastern white-winged dove breeds from southern Texas (south of Del Rio, Uvalde, San Antonio, Beeville) to Tamaulipas and overwinters from Oaxaca to Costa Rica but mainly in El Salvador; it also occurs in the Greater Antilles (Fig. 12).

The Big Bend white-winged dove is restricted to Presidio and Hudspeth Counties of Trans-Pecos Texas and nearby areas of Chihuahua (Fig. 11).

The western white-winged dove breeds from the lower one-third of Arizona and small adjacent areas of southeastern California and southwestern New Mexico to Sonora and northern Sinaloa. It overwinters in the western slopes of the Sierra Madre Occidental north of where the eastern whitewing overwinters (Fig. 12).

1. *asiatica*
2. *peninsulae*
3. *australis*
4. *grandis*
5. *monticola*
6. *alticola*
7. *mearnsi*
8. *palustris*
9. *insularis*
10. *collina*
11. *panamensis*
12. *meloda*



Fig. 11 Map showing the approximate breeding ranges of the 12 subspecies of white-winged dove. Map is adapted from Saunders (1968, by Gallucci 1978).

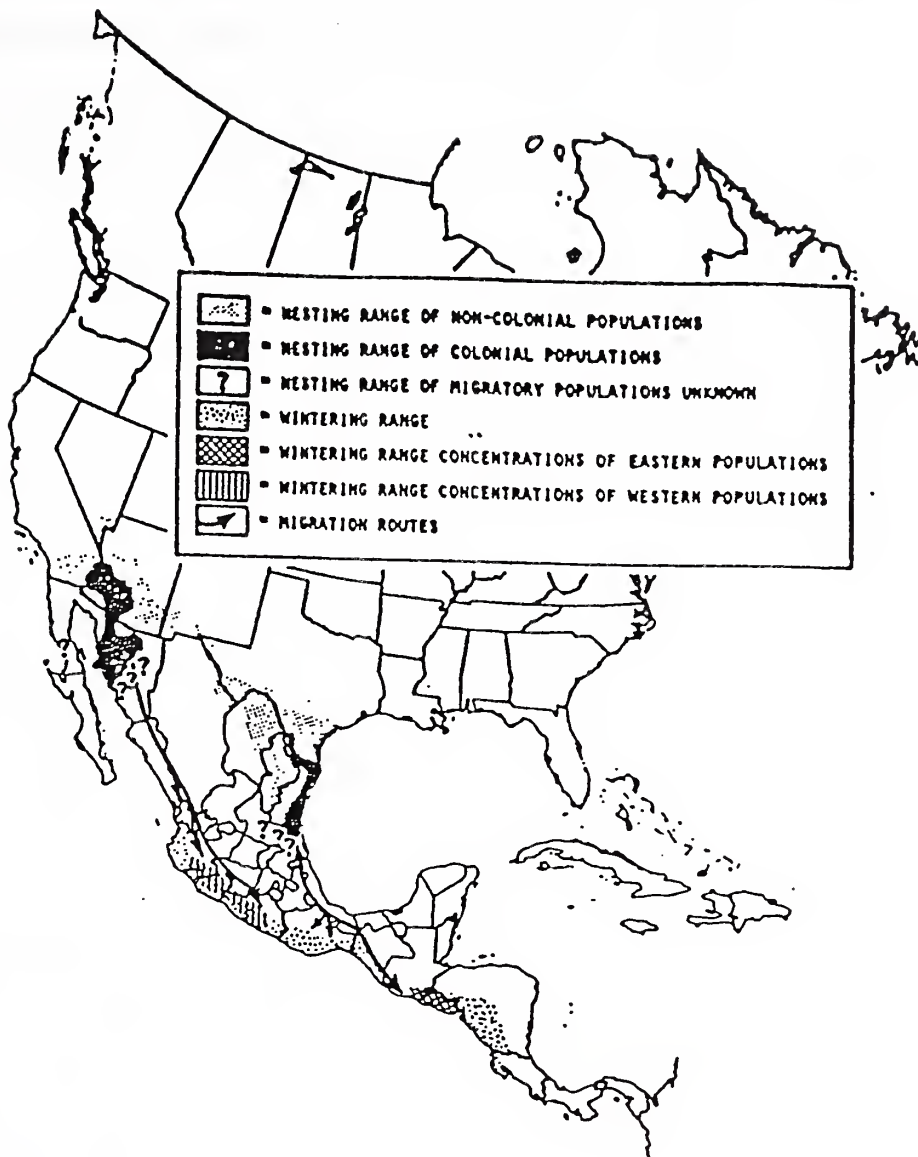


Fig. 12 The principal nesting and wintering areas of migratory white-winged dove populations in North America (from Brown et al. 1977a).

The Mexican highland white-winged dove barely crosses over into the lower Big Bend area of Texas and occurs throughout the central highlands of Mexico; it overwinters within its range except for the northern area (Fig. 11) (Saunders 1968, Cottam and Trefethen 1968, Brown et al. 1977a, Scudday et al. 1980).

2. Habitat Selection - Eastern Area.--The eastern white-winged dove is of great interest to dove hunters, but it is little influenced by saltcedar since the plant essentially does not occur in the area where the dove occurs. It is discussed briefly here to put the overall white-winged dove-saltcedar relationship in perspective.

The eastern whitewing, like the western whitewing, nests both in colonies in dense vegetation and in non-colonial populations in more disperse vegetation (Cottam and Trefethen 1968) (Fig. 12). Originally, and up to ca. 1940, it nested in extensive thickets of native trees and shrubs of the Lower Rio Grande Valley of southern Texas and much of Tamaulipas. The preferred nesting trees are the thorny Texas ebony (Pithecellobium), anacua (Ehretia anacua), huisache (Acacia farnesiana), colima (Zanthoxylum fagara), granjeno (Celtis pallida), and brasil (Condalia hookeri). Honey mesquite (Prosopis glandulosa var. glandulosa) is often dense in this area but has a more open canopy and is seldom used by whitewings (Cottam and Trefethen 1968, Brown et al. 1977a). Saltcedar does not grow in this area. Whitewings have increasingly moved to citrus groves and city trees. Nesting densities are much lower here, but the area is much greater.

Populations as high as 600 nesting pairs per acre have been recorded in top-quality native habitat. Citrus does not have the rough, thorny branches preferred by whitewing but the dense foliage is good. However, citrus groves are an uncertain habitat because severe freezes each 10-15 years kill the

majority of these trees in the Lower Rio Grande Valley. Disperse populations of whitewings nest in pecan, hackberry, live oak, and other trees in the cities (Cottam and Trefethen 1968).

Currently, 80% of the white-winged doves in Texas occur in the Lower Rio Grande Valley, estimated in May 1988 at 414,000. Of these, 71% were in native brush (25% of these in urban areas) and 29% were in citrus. Scattered colonies in upper south Texas (Lake Corpus Christi, Medina Lake, Del Rio) totaled 104,000 birds. Saltcedar does not grow in any of this area. Only 28,000 of the estimated 546,000 whitewings (5% of the total) occur along the Rio Grande west of Big Bend National Park (George 1988a). This is the only area in Texas where saltcedar is used as nesting habitat.

3. Habitat Selection - Western and Trans-Pecos Texas Areas.--The greatest concentration of western whitewings is in riparian thickets of the southern third of Arizona, particularly along the Salt, Gila and Lower Colorado Rivers. Nesting colonies in certain areas along these rivers reach very high densities and are very attractive to dove hunters. However, the bulk of the total whitewing population is widely dispersed over the thousands of square miles of desert scrub of the southern half of Arizona (Cottam and Trefethen 1968).

The western whitewing thrives in this area, which is the hottest and driest in the United States. The birds must have water but can fly up to 10 miles to watering sites. The number of sites has increased greatly in recent years due to windmills and wells constructed for cattle by ranchers and for wildlife by the Arizona Game and Fish Department. The preferred nesting trees are saltcedar, velvet mesquite, desert willow, and hackberry in riparian areas and ironwood (Olneya tesota), paloverde (Cercidium and Parkinsonia, and jito (Forchammeria watsonii) along desert washes (Brown et al. 1977a).

The white-winged dove occurs in six distinct habitats in Arizona (Cottam and Trefethen 1968):

Chaparral--This is a belt 50-75 mi wide by 150 mi long, from Globe to Seligman, of mixed shrubs 6 ft high or less. It is little used by whitewings because the shrubs are too low and the fruits ripen too late.

Desert grassland--Under "natural" conditions, this is very poor whitewing habitat. Today, however, the invading mesquite provides nesting sites, and food and water are available where cattle are fed.

Oak woodland (live-oak type)--This area in Pima and Santa Cruz counties, accounted for 13% of the Arizona whitewing in 1963 (Table 26). Most of the Arizona oak woodland lies outside the range of the whitewing and, since the 1880's, much has been replaced by mesquite of poor quality for nesting.

Table 26. Breeding density estimates for various habitat types, Arizona, 1963 (from Cottam and Trefethen 1968, Table 13).

Habitat	Acres	Birds per 10 acres	Estimated population
Mesquite <sup>a/</sup> thickets (Komatke and San Xavier)	1,500	200	30,000
Mesquite <sup>a/</sup> thickets (Lower Gila River)	20,000	10	20,000
Mesquite <sup>a/</sup> thickets (Lower Colorado River) (Mexico to Davis Dam)	100,000	22	220,000
Saltcedar thickets (Gila River-Phoenix- Gillespie Dam)	11,000	320	352,000
Oak woodland (Pima and Santa Cruz counties)	500,000	4	200,000
Cacti-palo verde type	7,000,000	1	700,000
Citrus	<u>30,000</u>	6	<u>18,000</u>
TOTAL	7,662,500		1,540,000

<sup>a/</sup> Velvet mesquite (Prosopis velutina).

Creosotebush desert--This vast area is of very little value for whitewings.

Cacti-paloverde--This is the most valuable habitat for the western whitewing after riparian areas (Cottam and Trefethen 1968). The abundant desert washes of this area are lined with scattered large trees of velvet mesquite, paloverde (Cercidium spp.), and ironwood. All of these are thorny leguminous trees with dense canopies that are excellent nesting trees. Whitewings also nest in the arms of the giant saguaro cactus (Carnegiea gigantea) that is common in certain areas. Although whitewing populations in these habitats are much more dispersed, 45% of all Arizona whitewings were found here in 1963 (Cottam and Trefethen 1968) because of the much large area. A reliable water source must be available within 8-10 miles.

Mesquite-saltcedar thickets (riparian)--Most of the mesquite in riparian areas of Arizona (except the lower Colorado and lower Gila Rivers and the southeastern mountain area) is velvet mesquite (Prosopis velutina). Most of the original velvet mesquite thickets are now gone (see Sect. VI,A,2). The famous Arizona whitewing hunting areas, where huge nesting colonies were located, were all in this habitat type. These were the San Xavier, Komatke, New York, and other thickets or "bosques" (Wigal 1973). Whitewing populations and kills by hunters have fallen drastically in recent years, prompting sports writers in the local newspapers to ask, "where have all the whitewings gone?". The last large stand of this type lies along the Gila River between the Highway 85 bridge and Gillespie Dam (AZG&FD, pers. comm.).

In Arizona, 26 million acres lie within the main area of whitewing distribution. Within this area the doves utilize several distinct habitat types (Table 27).

Table 27. Habitat types used by the white-winged dove in Arizona (from Wigal 1973).

Habitat type	Acres	Fledglings/ 100/A	Total population
Riparian	70,000	500	520,077
Citrus	34,000	175	96,910
Desert scrub	24,600,000	< 2	218,295
Oak woodland	1,100,000	< 1	5,796
TOTAL			841,078

The riparian areas are mainly along the Bill Williams, Colorado, Santa Cruz, Salt, and Verde Rivers and Pichacho Reservoir, the oak woodland in the southeastern mountains, and the citrus in Yuma and Maricopa Counties.

Cottam and Trefethen (1968) reported that (velvet) mesquite (Prosopis velutina) in Arizona is very good habitat, with whitewing densities of 10 nesting pairs per acre, while whitewings in the Lower Rio Grande Valley seldom nested in (honey) mesquite (P. glandulosa). This probably is because the velvet mesquite of Arizona has a much denser canopy than the honey mesquite of south Texas (Burkart 1976, Johnson 1963). Cottam and Trefethen (1968) reported that dense saltcedar or saltcedar-mesquite might have 200 nests per acre in localized areas. They gave whitewing densities and populations in various habitats (Table 26).

Wigal (1973) found the average nesting tree was 16.2 ft tall with a 75% crown cover of the stand. In citrus, trees less than 15 ft tall averaged 50 nests while those more than 15 ft tall average 419 nests per 100 acres. Along the upper Rio Grande of Texas, the average nesting tree was 27.8 ft tall and the average nest height was 16.7 ft (Gallucci 1978, Scudday et al. 1980). Anderson and Ohmart (unpubl. data cited by Butler 1977) found a good

correlation between foliage density and dove density in 19 plant communities on the Lower Colorado. Butler (1977) speculated that the reason for higher nesting densities was that dense vegetation had more nesting sites; also, he found less egg predation in species of trees with high foliage density and in parts of the same tree with more foliage. Anderson and Ohmart (1977b) found a highly significant preference of whitewings and mourning doves for dense vegetation at 3.0, 4.5 and 6.0 m high; the whitewing was more of a specialist for this type than the mourning dove.

Along the Lower Colorado River from Davis Dam to the US-Mexican boundary, whitewing density during the summer was highest in community types designated as screwbean mesquite, next in saltcedar, and next in cottonwood-willow (Anderson and Ohmart 1977b). The doves strongly preferred structural Type II in screwbean and saltcedar and densities were only 1/6 as great in structural types III and IV and still less in Types V and VI (Table 28). The preference for tree height or species is not clear in this study because all structural types have scattered taller shrubs and trees and several of the community types have a very mixed species composition (see footnote to Table 2 and Fig. 10). The data do not indicate which trees the doves inhabited within a community/structural type.

Butler (1977) compared whitewing reproduction along the Lower Colorado River in three riparian community types: 1) saltcedar (99%), 2) mixed saltcedar-screwbean (50% saltcedar, 59% screwbean, 11% arrowweed), and 3) (western) honey mesquite (75% mesquite, 1% screwbean, 0.3% saltcedar) (Table 29) (his "honey mesquite" was probably western honey mesquite). He proposed that fledging success was the most meaningful measure of habitat suitability. The mixed habitat was most favorable for whitewings, saltcedar next, and western honey mesquite least favorable.

Table 28. Density of the whitewinged dove from May through September in various community/structural vegetational types in the Lower Colorado River Valley, 1975-77 (from Anderson and Ohmart 1977b)<sup>a/</sup>.

Community type	Structural type (no. per 100 acres)						Mean
	I	II	III	IV	V	VI	
Screwbean		274.8	63.5	23.4	5.7	7.0	74.9
Saltcedar	13.8	141.6	16.5	27.4	6.8	38.8	40.8
Cottonwood-willow	25.8	37.8	21.0	42.6	18.2	10.4	26.0
Honey mesquite			44.0	13.2	3.0	3.5	15.9
Orchard	39.5	22.5	10.5	6.0			19.6
SC-HM				38.7			19.3
Marsh				17.5			8.8
Desert wash				6.0			3.0
Arrowweed						5.7	2.8
MEAN	26.4	119.2	31.1	21.8	8.4	14.9	

<sup>a/</sup> The sampling technique tended to underestimate dove populations, perhaps by 25%. See Sect. VII,A,2 and Fig. 10 for definition of C/S types.

Table 29. Reproduction and mortality of the white-winged dove in three riparian communities on the Lower Colorado River (from Butler 1977).

	Saltcedar	Mixed	Western honey mesquite
Nests per ha	28.0	34.0	17.5
Nest height (m)	4.85	3.5	4.05
Mortality (%)	15.5	8.1	10.8
No. eggs + nestlings	54.9	65.2	54.1
Avian predators <sup>a/</sup>	lowest	intermed.	highest
Fledgling success (%)	47.6	55.1	42.8
Productivity (fledglings/40 ha)	920	1531	631

<sup>a/</sup> Probably Gila woodpecker, cactus wren, and crissal thrasher, all predators of eggs.

In the Buckeye-Arlington area of the Gila River, AZ, whitewings nested almost exclusively in tall saltcedar while mourning doves preferred velvet mesquite but nested frequently in other trees (Cunningham 1986) (Table 30):

Table 30. Habitat preference for nesting doves in the Buckeye-Arlington area of the Gila River Valley, AZ (from Cunningham 1986, Tables 11 and 12).

Tree species	Number of nests	
	Whitewings	Mourning
Tall saltcedar	208	34
Medium saltcedar	0	49
Velvet mesquite + saltcedar	0	56
Velvet mesquite	0	208
Desert washes	0	4
Atriplex	0	3
Creosotebush	0	0

For whitewings, 91% of the variation in nesting was due to tall saltcedar; they built nests in the highest foliage density 2.5-6.0 m above the ground, where they had the highest success rate. This nest density declined by 25% each year and the time of nesting varied year to year. Mourning doves were more generalists in that they nested below the areas of densest foliage. This nest density was more stable, and they nested at the same time each year.

Webb (1967) found that, on the Gila River, whitewings strongly preferred reaches of the river that had mixed velvet mesquite-saltcedar while mourning doves favored reaches with less velvet mesquite (Table 31).

Along the Lower Colorado River, screwbean mesquite was the preferred habitat for whitewings, followed by saltcedar, then honey mesquite (probably western honey mesquite) and cottonwood-willow (Anderson and Ohmart 1977b, 1984a) (Table 32). The doves clearly preferred vegetation in structural

Table 31. Populations of mourning dove (MD) and white-winged dove (WW) on the Gila River from Safford to San Carlos, AZ, summer 1966 (from Webb 1967).

River reach	Habitat acres	% mesquite: saltcedar	Nests per 100 acres		Total adult doves in area	
			MD	WW	MD	WW
1	611	0:100	495	35	6,056	428
2	3,232	18:82	485	32	31,362	2,070
3	<u>2,764</u>	40:60	69	76	<u>3,830</u>	<u>4,196</u>
TOTAL	6,607				41,248	6,694

class II (mostly 15-25 ft high) and might have been more numerous in western honey mesquite had stands of this height been available. "Dove" density decreased as higher-level foliage density decreased but increased with increasing density of screwbean mesquite. The "doves" preferred trees of varying densities and 15-25 ft high, but trees taller than 40 ft negatively affected density.

Anderson et al. (1977a) also noted that in this same area "doves" had a strong preference for dense vegetation at a height of 3-6 m for nesting. They found that half of all birds in saltcedar during the summer were doves but, nonetheless, there were more doves in other plant communities than in saltcedar. This contrasted sharply with the situation on the Gila River near Buckeye-Arlington (Cunningham 1986) (see Table 30).

The growth form of seepwillow (Baccharis salicifolia = B. glutinosa), which was abundant in riparian habitats before the invasion of saltcedar, is too low for any but minor use by whitewings (Cottam and Trefethen 1968).

Along the Rio Grande between Ft. Quitman and Haciendita, TX, Engle-Wilson (1978a) found that the Big Bend white-winged dove was the only bird with a strong preference for saltcedar and saltcedar ranked only 4th out of 7 vegetation types. Whitewings were the only species with a narrow habitat

Table 32. Densities of the white-winged dove along the Lower Colorado River (summarized from Anderson and Ohmart 1977b).

Community type <sup>a/</sup>	Number per 100 acres (3-yr avg.) in vegetation structural type: <sup>a/</sup>					
	I	II	III	IV	V	VI
-----March-April-----						
Cottonwood-willow	2.3	2.0	1.3	2.0	1.5	1.0
Screwbean-mesquite		2.7	13.0	1.0	1.7	
Western honey mesquite			2.0	2.3	0.3	.7
Saltcedar	1.0	3.5	0.5	0.3	1.3	1.3
Western honey mesquite-saltcedar				1.3		
Arrowweed						0.3
Marsh						
-----May-June-July-----						
Cottonwood-willow	48.3	71.0	28.0	30.3	26.0	16.3
Screwbean mesquite		413.7	78.3	29.7	9.7	11.0
Western honey mesquite			59.7	20.3	5.3	6.3
Saltcedar	25.5	213.3	28.0	48.7	12.0	19.0
Western honey mesquite-saltcedar				26.0		
Orchard (1 yr)	79.0	45.0	19.0	5.0		
Desert wash (1 yr)				6.0		2.0
Arrowweed						5.7
Marsh				10.0		
-----Aug-Sept-----						
Cottonwood-willow	3.3	4.5	14.0	55.0	10.5	4.5
Screwbean mesquite		136.0	48.7	17.0	1.7	3.0
Western honey mesquite			28.3	6.0	0.7	0.7
Saltcedar	2.0	70.0	5.0	6.0	1.7	58.7
Western honey mesquite-saltcedar				12.7		
Orchard (1 yr)			2.0	3.0		
Desert wash (1 yr)				0		1.0
Arrowweed						
Marsh			7.5			

<sup>a/</sup>

I=peak foliage &gt;9 m, moderate understories

II=moderate foliage 6-9 or 9+ m, peak at 4.5-6 m

III=little foliage 6-9 m, peak at 3.0-4.5 m

IV=rare foliage 6-9 m, peak at 1.5-3.0 m

V=little foliage 4.5-6.0 m, peak at 0.0-3.0 m

VI=little foliage 3.0-4.5 m, peak at 0-1.5

breadth that preferred saltcedar. He found an average of 28.4 nests/A in saltcedar. Gallucci (1978) and Scudday et al. (1980), in the same area, reported a production of 2600 young per 100 A in 1977 but only 1000 per 100 A in 1978. Engle-Wilson (1981), along three Arizona rivers, found 3.80 whitewing nests per plot in saltcedar and only 0.68 per plot in mesquite (mean of 2 locations each): other birds strongly preferred mesquite (see Sect. VII,A,6).

4. Habitat Selection - Northwestern Mexico (see Appendix III).---In the northern part of northern Sinaloa in the Rio Fuerte basin and in the Municipio of Choix in the mountains, the whitewing nested primarily in mangrove swamps (82% of the population), orchards (11%), along the Rio Fuerte (1.3%), and in open woodlands (Martinez-Lopez 1986). It preferred red mangrove over the white. These trees increased in height from 1-2 m inland to 8-10 m toward the sea. Whitewings nested mostly in trees 3-10 m high, both in colonies and dispersed. In orchards, they preferred orange (avg. 5 nests/tree), grapefruit, mango (2 nests/tree), and avocado.

Along the river, the birds nested in cottonwoods, willows and shrubs. Along the dams and dikes, they nested in mesquite, Acacia, willow, and cottonwood. Here, nests averaged 3-4 m high and 100 m apart.

In the open woods, they nested in (velvet?) mesquite, guamuchil, prickly pear, and pitayas in little-disturbed hills and arroyos (Martinez-Lopez 1986).

Along the Rio Fuerte, 112 whitewing nests were counted in the following trees (Martinez-Lopez 1986):

Mesquite	34	<u>Acacia millifolia</u>	4
Vinorama	25	Willow	4
<u>Pithecellobium dulce</u>	11	<u>Baccharis glutinosa</u>	1
Guayacan	4	11 other plant species	1-3 nests each
<u>Opuntia</u> spp.	4		

Saltcedar apparently does not grow in this area and no whitewings were reported nesting in it.

Scudday (Appendix III, this report) measured usage of saltcedar by the white-winged dove in northern Sinaloa and Sonora, Mexico, during two trips, make May 11-21, 1987 and May 20-31, 1988. He found that saltcedar had spread as far south as Los Mochis and Topolobampo in Sinaloa but not a little farther south at Guamuchil. In these more southern areas, the plants were only 1 to 3 years old. Near Hermosillo, Sonora, they established a 27.3-acre plot within the floodplain of the A. Rodriguez reservoir on the Rio Sonora that consisted of a dense growth of saltcedar with some athel, Cercidium sp., blackbrush (Acacia rigidula), bermudagrass, and Baccharis sp. The saltcedar did not form a closed canopy; only a few trees were taller than 20 ft and most were less than 15 ft tall.

These developing saltcedar thickets were utilized much more extensively by birds than by any other group of vertebrates. Grackles were the dominant bird in the saltcedar; male great-tailed grackles used the taller and more mature athel trees from which to call and display. However, no nests of grackles were found in the area.

Only doves of three species were found to have nests within the saltcedar thicket. A census on the three acre study plot revealed 14 ground dove nests, 7 mourning dove nests, and 7 white-winged dove nests, all active. Either doves did not nest at this site last year or the flimsy nests did not survive the intervening winter.

Scudday (Appendix III, this report) estimated the population of all doves at 27+ nests/ha (9+ nests/acre) including 2.3 white-wing nests/A. The survey was taken fairly early in the year for nesting birds, and the density of nesting birds might have increased as the season progressed.

Nesting whitewing densities were much lower than those reported in fully mature type I and II saltcedar trees along the Rio Grande in Texas (Scudday et al. 1980; Engel-Wilson and Ohmart 1978a) where from 15 to 35 nests/acre were found. All nests encountered in Hermosillo were located in the densest part of the thicket, and no nests were found around the perimeter of the stand, possibly because intense human activity around the edge of the thicket discouraged nesting there. Whitewing nests were found in saltcedar trees 4- to 15-ft tall and in willow and blackbrush trees.

Scudday (1989) noted the occurrence of saltcedar and white-winged doves in several other areas. From Immuris to Santa Ana (northern Sonora), native shrubs such as cottonwood, willow, mesquite, and Acacia occupied the whole floodplain but saltcedar was not present; white-winged, mourning and ground doves were common.

From Santa Ana to Coborca, little saltcedar was present but whitewings were abundant, nesting in native shrubs.

Near Ciudad Obregon (southern Sonora), much young and some older saltcedar was found, with dense native vegetation. Many white-winged doves were found here but they (and the other bird species) were mostly in the native vegetation.

Near San Blas (northern Sinaloa), many whitewings were seen along the Rio Fuerte to Babu, mostly in native vegetation, but not in a dense 27 ha stand of saltcedar just north of San Blas.

5. Migration and Annual Cycle.--The eastern whitewing begins flying north from the overwintering areas in late February or March. They fly mostly in the early morning, in groups of a few to 50, and sometimes 3000 to 4000 can be seen flying at once through eastern Mexico between the coast and the mountains. These flights are direct and "purposeful," with little

dawdling around (Cottam and Trefethen 1968). They arrive at the breeding areas of Tamaulipas and southern Texas from March to early April (sometimes late February).

The older birds arrive at the nesting sites first, and by mid-May nearly all are present, though the young birds continue arriving into June (Cottam and Trefethen 1968). Nesting and rearing the young continues until about August 15; the young remain near the nests for another two weeks, being fed by the parents.

In the southern nesting area near Cd. Mante and San Jose, Tamaulipas, the birds finish nesting in late June or July then move north to feed near San Fernando and by late August or September to the Lower Rio Grande Valley; one of these banded birds was taken at San Antonio (Blankenship et al. 1972). Most birds apparently return to the original nesting grounds, though the young birds disperse more widely. They will move to a different location if the nesting habitat is destroyed. Of 71,674 whitewings banded in Tamaulipas from 1966 to 1970, 1063 were recovered (Blankenship et al. 1972). Of these, 704 (66%) were recovered in Tamaulipas, Texas, and Nuevo Leon and 256 (24%) from Central America (mostly El Salvador).

Some of the Texas birds may reenter Mexico after nesting and return to Texas again after 2-4 weeks when food in Texas matures (Cottam and Trefethen 1968). The first birds begin drifting south about September 1, the adults leaving first, but most are still present when the hunting season begins on September 1. Departure of large numbers may be abrupt or extend over several weeks, and some birds remain until early October, but mass flights are rare. A shortage of food, heavy hunting or a cold north wind or rain causes large departures. They move leisurely along the way, down the eastern slopes of Mexico and across the Isthmus of Tehuantepec, taking several weeks

to arrive. The major wintering grounds are in El Salvador but they also overwinter in Oaxaca, Chiapas, Guatemala, Honduras, and Costa Rica (Brown et al. 1977a). They overwinter in thorn forests of the coastal plain, foothills and mountains and in mangrove swamps. This habitat appears plentiful and not threatened in the foreseeable future.

They breed from northern Vera Cruz and northeastern Coahuila through Tamaulipas, Nuevo Leon and Lower Rio Grande Valley of Texas to Del Rio, San Antonio and Corpus Christi, and also in the Greater Antilles (Cuba, Hispaniola, and Jamaica) (Figs. 11, 12) (Cottam and Trefethen 1968, Goodwin 1977, Blankenship et al. 1972, Brown et al. 1977).

The western whitewing overwinters along the Pacific slopes of Mexico in Colima, Jalisco, Michoacan, and Guerrero, which lies north of the overwintering area of the eastern whitewing (Fig. 12).

They begin migrating northward in March preceded by heavy flocking and feeding. The southernmost breeding area appears to be in northern Sinaloa (Martinez-Lopez 1986), considerably south of the zone given by Brown et al. (1977a) (Fig. 12). In Sinaloa, courting for the first brood takes place the first half of April and egg laying the second half of April to the first days of May. For the second brood, courting takes place the last of May to mid-June and egg laying from the end of June to the end of July (Martinez-Lopez 1986).

In Arizona, the birds begin arriving in early March with the population crest about May 20 (Cottam and Trefethen 1968). The nesting cycle is similar to that of the eastern whitewing, but they begin the fall migration earlier. They begin flying south in early August and many have left by the time the hunting season begins on September 1. Only isolated small flocks and strays remain after the hunting season although some remain until October and a few

even overwinter in Yuma (Anderson and Ohmart 1984a). They migrate through the mountains and pass rapidly through Sonora (Cottam and Trefethen 1968). However, Martinez-Lopez (1986) found that they remained a long time in Sonora and Sinaloa in agricultural areas, feeding in grain fields where they are regarded as a pest by the local farmers.

The Big Bend whitewings follow a similar cycle in Trans-Pecos Texas but appear to be less migratory. The first arrive at Presidio in late February and most have returned by mid-March. After the breeding season, large populations are found at Rio Grande Village and Basin in Big Bend National Park and in other areas. The hunting season disperses some but large numbers are present sometimes through October and at Presidio into December. Some overwinter in the Alpine area where they move into protected canyons during severe cold weather. The overwintering locations in Mexico are unknown (Scudday et al. 1980).

6. Nesting.--The white-winged dove prefers to nest in the interior of dense stands of vegetation with near 100% canopy area, in trees 15-30 ft tall, of tree species that have dense branches and foliage (Phil Smith, Ron Engle-Wilson, and Stan Cunningham, Arizona Game and Fish Department; Ron George, Texas Parks and Wildlife Dept; pers. comm., January 1989; Butler 1977). Such habitat formerly was common in Tamaulipas, in northern Sinaloa and Sonora, in riparian areas of the Lower Rio Grande Valley, and in several rivers of the southern third of Arizona. In these preferred habitats, they form large, dense nesting colonies that are highly favored by hunters.

In areas of favorable trees, but of more sparse stands, whitewings nest in dispersed populations rather than in colonies. In Arizona, citrus trees less than 15 ft tall had an average 50 nests per 100 acres while taller trees had 419 nests per 100 acres (Wigal 1973). In the Buckeye-Arlington area of

the Gila River, nests were placed 3-6 m high in the densest foliage of saltcedar (Cunningham 1986). Average nest height was 4.8 m in saltcedar, 4.0 m in mesquite, and 3.5 m in mixed saltcedar-mesquite stands along the Lower Colorado River (Butler 1977). Along the Rio Grande of western Texas, the mean height of nest trees was 27.8 to 28.8 ft and nests were located 7-27 ft (mean 16.7 to 17.5 ft) high (Engle-Wilson and Ohmart 1978a, Gallucci 1978, Scudday et al. 1980). Near Hermosillo, Sonora, Scudday (Appendix III, this report) reported that the height of whitewing nests was 4-15 ft (mean 10 ft) in a stand of mostly small trees.

Upon arrival at the summer breeding areas from the overwintering locations in southern Mexico, the male selects and defends a territory which attracts a female. Nest building begins immediately; the female selects the specific site, the male brings sticks, and the female builds the nest, which is completed in 2-5 days. The first egg is laid within hours of nest completion and the second ca. 36 hr later. A normal clutch is 2 eggs although only 1 (especially if food is scarce) or as many as 3 (or rarely 4) may be laid. Incubation requires 14 days with another 13-16 days before the young leave the nest. Females brood the eggs at night, the males fly out to feed at dawn and return ca. 8:30 am. They then brood the eggs and the females fly out to feed, returning ca. 3:30 pm. The females then brood till the next morning and the males fly out to feed again in the afternoon, returning at sunset.

The young are fed on "pigeon milk" secreted by the crop of both parents, usually also mixed with some seeds from the crop. After leaving the nest, the young remain in the vicinity of the nest for another ca. 2 weeks, being fed at least daily by the parents. When they reach one month old, they join the adult feeding flights. As soon as the young leave the nest, the adults begin another brood, sometimes in the same nest. Up to 5 broods may be

started during the breeding season, especially if some are lost to predators or storms. Two or sometimes three broods may be reared (Cottam and Trefethen 1968). Behavior in Sinaloa is similar, with the first brood produced the last half of April and the first of May and the second brood from the end of June to the end of July; the parents usually used the same nest for the second brood (Martinez-Lopez 1986).

In southern Texas, whitewings used the same nest only once in 82.6% of the cases, twice 15.4%, and three times 0.1%, among 2285 nests examined over a 6-year period. Only 46.6% of the active nests were occupied at the peak of the nesting season (Cottam and Trefethen 1968).

After the breeding season, the doves may change their roosting sites every few days, returning after a few weeks to a previously used site. In west Texas, they usually roost on trees or ocotillo near water in groups of up to 500. In the early morning, they go to drink; then they break up into groups of 3-10 and fly into the hills to feed. They return in flocks of 10-30 just before sunset (Scudday et al. 1980).

7. Feeding.---The white-winged dove feeds in fixed behavior patterns, both in time and space, which makes them easy to shoot at feeding sites. This, together with their colonial nesting behavior and large flocks, mostly contributes to their popularity with hunters.

Whitewings do not feed within the dense forests of the nesting colonies but fly out to feed at favorite grain fields, areas of native food plants, or watering sites that can be located 10-25 mi away. They fly in many small groups of 8-10 birds. The males (or females) of the whole colony may fly at the same time, with 5000 or more birds arriving within a short time (Cunningham 1986). They habitually return to the same grain fields until

they have eaten it all, often flying over and ignoring other good grain fields along the way (Cunningham 1986).

In Arizona, whitewings congregate in large numbers at the few habitual watering sites, bypassing new water sources. For both food and water, they appear to be programmed to return to a specific site rather than to look for the nearest supply. In south Texas, favored native foods are the fruits of granjeno (Celtis pallida), anacua, coma (Brumelia), colima, brasil, privet, pigeon berry (Rivina), and seeds of doveweed (Croton), sunflower (Helianthus), spurges (Euphorbia), leatherweed (Jatropha), and other plants. Favorite agricultural crops are grain sorghum and other cereal grains (Cottam and Trefethen 1968).

Along the Rio Grande of western Texas, crop analysis showed the following foods (Engle-Wilson and Ohmart 1978a, his Table 10):

May:	wheat 82%, other seeds 13%
June:	wheat 71%, white-thorn acacia 13%
July	leatherstem 99%
Sept	leatherstem 94%

In the same area, Scudday et al. (1980) also reported that leatherstem seeds were the favorite food. From the time they ripen in late summer through February, they constitute 90% or more of the volume of the crop. In 1978, few leatherstem seeds were produced and the whitewings left the valley. In the spring, they ate seeds of catclaw (Acacia constricta) and lesser amounts of A. gregii. They also ate seeds of Euphorbiaceae and Leguminosae, seeds from horse manure, seeds from dumped cantaloupes, and grain when available. Doveweed (Croton sp.) was common, but whitewings did not eat these small seeds although mourning doves ate them readily. In the Chinati Mountains, whitewings ate substantial amounts of acorns.

In Arizona, natural foods are seeds of Croton, Bursera and Viguiera. In agricultural areas, they ate almost entirely grain (97.2% of diet) (Cunningham 1986).

In earlier years, whitewings in Arizona caused considerable damage to grain fields by their feeding. Farmers sometimes invited hunters to protect their crops. Each bird eats ca. 3/4 oz. of grain/day; thus, a large flock of 400,000 doves would consume 4-1/2 tons of grain daily. They frequently return continuously to the same fields until all food is consumed (Cottam and Trefethen 1968). Farmers in Sinaloa also try to protect their grain fields from whitewings by scaring them with firecrackers, shooting or trapping them with nets or cages and poisoning them with poison grain issued for rat control (Martinez-Lopez 1986).

8. Mortality and Natural Enemies.--Mortality to squabs in the nests is easily measured and has been well documented. However, mortality of immatures after leaving the nest (often on the ground) or of adults, from causes other than hunting, is very difficult to determine. Overall population estimates before and after the breeding season give the overall rate of increase at that time, but the methods that must be used contain considerable error. Recoveries from banding give migration routes and overwintering areas but are too few to give estimates of mortality. Maximum known age of a wild banded bird is 15 years and of a captive bird, 25 years (Cottam and Trefethen 1968).

In the Lower Rio Grande Valley of Texas, fledgling success in colonies was usually ca. 30% and in dispersed sites ca. 50%. Losses from predators was generally higher in colonies and at times approached 100%. Greatest losses were from great-tailed grackles and to a lesser degree from green jays. These predators are attracted in large numbers to the colonies and

eat the eggs or kill the young squabs up to the age of 8 days. They are particularly effective when the male dove leaves the nest to drive off another invading male, which is more frequent in denser colonies. Mammalian predators (e.g., ringtailed cats, opossums, raccoons, rats) take lesser numbers of squabs, mostly those on the ground, since the thorny trees give considerable protection against climbing predators. Predation by rats is sometimes heavy in trashy citrus orchards, and house cats may eat many squabs in towns. Climbing snakes and ants may also eat many squabs at times (Cottam and Trefethen 1968).

External parasites (louse flies [Hippoboscidae], mosquitoes, ticks) are common but seldom cause death of squabs. Internal parasites also exist but probably do not cause much loss. Infection by the protozoan Trichomonas gallinae may be very high but appears mostly non-virulent. Birds are also infected with several other pathogens but losses do not appear great. Territorial strife with other whitewings is constant and often severe in the dense colonies but causes little loss; however, it allows great indirect loss by leaving the nests exposed to grackles and jays (Cottam and Trefethen 1968).

Although little information was available on mortality in the western area at the time, Cottam and Trefethen (1968) speculated that losses from mammalian predators was substantially less. Also, the thinly dispersed populations in the vast cacti-paloverde habitat are probably little attacked by grackles and jays which do not usually inhabit these areas. Nests in saguaro cactus would be practically immune from climbing predators. Even external and internal parasites are probably less of a problem in these areas.

On the Gila River, Arizona, whitewings nested about equally in saltcedar at Powers Butte and in mesquite at Pima Butte, 40 miles away, but fledgling success was drastically different (Wigal 1973, his Table 4):

	<u>Nests/100 A</u>	<u>Egg Mort.</u>	<u>Fledglings per nest</u>
Mesquite (Pima Butte)	3,040	71%	0.46
Saltcedar (Powers Butte)	3,410	42%	1.04

The major reason for the difference seemed to be egg mortality which, in other studies, was due mostly to avian predators, which Wigal did not count. Nesting success in citrus, 1.04 fledglings per nest, was greater than in riparian areas.

On the Lower Colorado River, Butler (1977) compared reproductive parameters in 3 vegetation types: 1) mixed saltcedar-screwbean (49.7% saltcedar, 59.2% screwbean, 11.4% arrowweed); 2) saltcedar (99%); and 3) mesquite (75.2% mesquite, 1.0% screwbean, 0.3% saltcedar) (Table 29). He noted that nests located in areas of higher foliage density had less predation. Both the number of small avian predators and the overall rate of predation was highest in mesquite, intermediate in saltcedar-screwbean, and lowest in saltcedar. The principal predators were probably the Gila woodpecker, cactus wren and crissal thrasher---all egg predators. Large avian predators probably caused very little loss, and snakes may have eaten some eggs and young; woodrats (*Neotoma albigula*) were abundant, but he saw no evidence of predation. Hatching failure was 6.8% in 1974 and 5.5% in 1975, which is similar to that of other birds. Weather was not severe enough to cause much loss.

Climatic factors directly or indirectly can cause heavy losses of the eggs and nestlings at times. Storms sometimes cause the nests to fall or cause the eggs or nestlings to fall from the nest (Cottam and Trefethen 1968, Martinez-Lopez 1986). Along the Rio Grande of western Texas, Gallucci (1978) documented a case where all nests were abandoned and nearly all the chicks were dead. He believed this was caused by hordes of mosquitoes that

developed in pools of water following an unusually heavy rain. Also, the flood following this rain produced a 36-ft crest that destroyed the nests and young in some areas. Gallucci (1978) reported a 39.0% fledgling success rate in this area in 1978, compared with a 48.6 success rate by Engle-Wilson in 1977; this, together with much lower egg production in 1978, produced only 1000 young per 100 acres compared with 2600 in 1977.

In Sinaloa, Martinez-Lopez (1986) listed nest abandonment in areas frequently disturbed by man, along roads, etc., as an important mortality factor. Predators listed were iguanas, boas, raccoons, and badgers. Very few eggs were infertile. Nests in mangrove swamps had good protection from ground-dwelling predators.

#### 9. Populations and Hunting - Eastern Area.

a. Methods of estimating population and hunting.--Several methods have been used to estimate whitewing populations. The most accurate is to count nests, adults on nests and eggs or young in the nests 15 to 25 ft on either side of a line, usually ca. 1 km long. Wigal (1973) found that beyond 17 ft from the center line, more than half of the nests were missed by the counting personnel. The contents of the nests can be examined with a mirror mounted on an extendable pole. This method was used by Butler (1977), Cunningham (1986), Engle-Wilson and Ohmart (1978a,b), Gallucci (1978), Martinez-Lopez (1986), Webb (1967), and others. This method is time consuming.

More rapid, but less accurate, population estimates can be made from call-counts or the noise level of the mass calls. Viers (1970) correlated calls with populations. Wind, rain or clouds had no effect on call rate, but unmated birds called 2.35 times/minute compared with 1.41 calls/minute for mated birds. Thus, calling was higher before or after a nesting cycle

than during the cycle. Other methods are to count birds in feeding flights or at watering sites. Waggerman (1974-88) described the call-count method used in surveys by the Texas Parks and Wildlife Department (TP&WD).

Whitewings bagged annually by hunters were measured by TP&WD through 1975 by counting the number of cars presumed to be hunter's cars parked in hunting areas from a small airplane from ca. 3:30-5:30 pm on each day of the hunting season. In addition, Department personnel monitored hunter's cars on the ground to count number of hunters per car and their hunting success (Dunks 1977).

In 1975, an extensive, self-administered mail survey was conducted by Mazzaccaro (1980), a Texas A&M University graduate student, to compare hunter days and number of whitewings bagged with the methods used by TP&WD. The results indicated that the previously used survey methods greatly underestimated actual hunting (Table 33).

Table 33. Comparison of self-administered mail survey with aerial survey of hunter cars for estimating dove hunting in the Lower Rio Grande Valley, Texas (from Mazzaccaro 1980).

	Mail survey	TP&WD aerial survey	Difference
-----Mazzaccaro survey (1975)-----			
Hunter days	109,587	36,500	200%
Harvest (whitewings)	591,926	121,500	387%
Harvest (mourning)	775,903	39,600	1,859%
-----TP&WD survey (1976)-----			
Hunter days	89,489	36,612	144%
Whitewings bagged	460,012	162,914	182%

As a result of Mazzaccaro's (1980) study, the TP&WD developed a mail questionnaire during the 1976 season which was sent to 2656 hunters that

bought whitewing stamps; a 68.1% return was obtained (Dunks 1977). The survey indicated that 91% of those persons who bought stamps actually hunted. This survey also indicated that the traditional method greatly underestimated actual hunting, probably because all hunter cars cannot be counted from the air (some are in transit, in isolated, under trees, etc.) (Table 33). In subsequent years, the survey was done by mailing ca. 2000 questionnaires to hunters.

b. Populations and hunting - Eastern area.--Early records of whitewing populations are very inexact. The early biologist in south Texas mentioned whitewings as being abundant with populations "in the millions" (Cottam and Trefethen 1968). The 1916 regulations allowed hunting from September 1 through March 1, with a limit of 15 "doves" per day. A peak population of 4-12 million was reached in 1923, caused by the introduction of irrigation and grain farming that provided food for the birds (George 1985) (water was always available from the river nearby). Between World War I and 1940, several hundred thousand acres of brush were cleared to plant cotton and other crops, and the drought of the 1930's made conditions worse for the birds. In 1936, the season was confined to September and October. Nevertheless, populations dropped to 500,000 in 1938 and to 200,000 by September 1, 1940.

In 1941, the season was reduced to 5 afternoons between September 15 and September 25. Since 1946, the season has been reduced to 3 or 4 afternoons, the starting time varying from noon to 4:00 pm and continuing till sunset. Bag limits usually have been 10-12 per day; in some years following severe freezes of citrus, the season has been closed.

Since 1947, the Texas Parks and Wildlife Department has conducted surveys of white-winged and mourning dove populations, reproductive success,

Table 34. White-winged dove breeding populations, percent nesting in citrus (the remainder in native brush or in cities), and harvest by hunters in the Lower Rio Grande Valley or the entire state of Texas (from annual reports of the Texas Parks and Wildlife Department).

Year	Spring breeding population	Population increase or decrease (%)	% in citrus	No. bagged	No. hunter days	No. bagged per hunter day
1947				44,868	13,063	3.43
1948				144,362	21,657	6.67
1949				218,365	29,940	7.55
1950	1,039,000			203,440	28,721	7.08
1951**	110,000			27,883	19,139	1.46
1952	214,000			117,324	19,735	5.94
1953	137,000			28,514	14,300	1.93
1954	115,000			Season closed		
1955	142,000			Season closed		
1956	234,000			Season closed		
1957	334,000			115,249	14,821	7.78
1958	245,000			83,145	16,303	5.110
1959	338,000			104,838	15,150	6.92
1960	441,000	+31	62	21,108	9,340	2.86
1961	592,000	+34	65	49,140	10,539	4.66
1962	301,000	-49	23	114,789	16,281	7.05
1963**	277,000	-8	32	Season closed		
1964	633,000	+129	52	239,097	33,972	7.04
1965	604,000	-5	41	145,108	29,477	4.9
1966	805,000	+33	47	233,735	38,544	6.1
1967	667,000	-17	46	282,136	36,012	7.8
1968	521,000	-22	44	220,692	42,050	5.2
1969	416,000	-20	47	100,693	18,140	5.7
1970	618,000	+48	57	85,311	20,066	4.2
1971	525,000	-15	65	78,586	15,136	5.2
1972	475,000	-10	63	166,629	23,097	7.2

Table 34. (continued)

Year	Spring breeding population	Population increase or decrease (%)	% in citrus	No. bagged	No. hunter days	No. bagged per hunter day
1973	525,900	+10	63	136,619	23,194	5.9
1974	529,000	+1	64	238,614	34,449	6.9
1975	693,000	+31	58	121,494	39,000	3.1
1976*	516,000	-25	63	483,095	98,678	4.9
1977	457,000	-11	61	438,195	78,093	5.6
1978	451,000	-1	56	305,443	88,886	3.6
1979	585,000	+30	62	499,816	91,216	5.5
1980	508,000	-13	56	214,259	83,949	2.6
1981	488,000	-4	49	262,265	86,179	3.0
1982	487,000	-1	42	390,658	90,869	4.3
1983	577,000	+18	44	273,434	90,980	3.0
1984**	469,000	-19	52	272,400	71,505	3.8
1985	361,000	-23	32	Season closed		
1986	472,000	+31	34	131,278	37,157	3.5
1987	421,000	-11	26			
1988	414,000	-2	30			

\* Began mail surveys of hunting rather than aerial surveys of hunter's cars; also, includes entire state rather than Lower Rio Grande Valley only as in previous years.

\*\* Years of freezes that killed citrus trees.

and harvest by hunters (Waggenerman 1974-1988, Cottam and Trefethen 1968, (Table 34). Populations gradually improved after 1946, partly because of the reduced hunting season and partly because of increased nesting in citrus, while citrus production had increased from 3000 boxes in 1919-20 to an all-time peak of 30.5 million boxes in 1946-47 (Cottam and Trefethen 1968).

A hard freeze during the winter of 1950-51 killed 85% of the citrus trees, and in the spring fewer than 110,000 whitewings nested in the valley.

~~Five years were required for the populations to recover, then another freeze~~  
 in 1962 again killed much of the citrus and caused whitewing populations to decline to half the 1961 level (Table 34).

Hunter days remained relatively stable at an average of ca. 17,500 from 1947 to 1962 (not counting years when the season was closed), but doubled to 34,500 from 1964-67. Dove populations also increased during that period, as did the number bagged, to an average 225,000/year bagged, or 34.5% of the fall dove population, with an average 6.4 birds bagged per day (Table 34).

With improved management by the Texas Parks and Wildlife Department, careful regulation of the hunting season and no disastrous freezes of the citrus trees, whitewing populations in the "Valley" increased after 1963 to stabilize by 1983 at ca. 500,000 pre-breeding season adults. These populations may fluctuate plus or minus 1-30% annually (Table 34). About half of these are in the 19,800 acres of brush (half of this within towns) and half in the 33,800 acres of citrus (Wagberman 1974-88). However, since 1983, populations have decreased by one-fourth and the proportion of citrus has also decreased. The 1982 freeze reduced the number of citrus trees by 52% (George 1988a).

After the mail survey began, the more accurate measure of hunter days was an average 88,600 per year and an average bag of 358,400 whitewings from 1976 to 1983; however, the bag has declined by 43% during that time.

In upper south Texas, major colonies at Del Rio, Uvalde, Medina Lake, and Lake Corpus Christi total ca. 104,000 birds (George 1988a). Usually, only ca. 16% of the whitewings were bagged in upper south Texas (Lake Corpus Christi, Medina Lake, Uvalde, etc.) and the rest, from the Lower Rio Grande Valley. Ron George (pers. comm. 1990) indicated that although the total of 1,000,000 whitewings in Texas is the best estimate, the distribution has

changed somewhat. Proportionally fewer now breed in the Lower Rio Grande River Valley (perhaps 300,000 now) and the scattered more northern colonies are larger. For example, an estimated 200,000 now breed within the city limits of San Antonio.

Gallucci (1978) estimated population of the Big Bend whitewing at 20,355 birds in Presidio County, and George (1988a) estimated populations along a 12-mile strip of saltcedar in the entire Trans-Pecos area at 28,000 birds. Recently, Ron George (pers. commu. 1990) estimated that whitewing populations in the Trans Pecos area could be 150,000 to 300,000 because whitewings are known to occur in several other strips of saltcedar that occur from Ft. Quitman (ca. 100 miles east of El Paso) to Falcon Lake; however, no additional counts of whitewings have been made and the location of all areas of saltcedar is not known either.

The total whitewing population of northeastern Mexico is estimated at 18-19 million birds (George, TP&WD, pers. commu., Jan. 1989). Most of the hunters in northeastern Mexico are from the United States; Mexican citizens only rarely hunt doves (Cottam and Trefethen 1968). However, Brown et al. (1977a) pointed out that hunting there had increased greatly at the expense of hunting in Texas, but the hunting season in Mexico was changed in 1971 from August 1 to September 1. They suggested that the Texas lower valley habitat could potentially support 500,000 to 800,000 whitewings and ca. 25% of these could be harvested annually, though heavy hunting across the river in Mexico would affect hunting in Texas. The new data available from the mailed questionnaire indicates that this amount has already been safely surpassed.

10. Populations and Hunting - Western Area.--The "original" abundance of the western white-winged dove in Arizona is uncertain. The early biologists

who accompanied expeditions in the 1850's through the 1870's mentioned whitewings as only "occasional" or "common" (Cottam and Trefethen 1968). The great velvet mesquite "bosques" along the rivers, which provide excellent habitat for nesting colonies, were intact before agriculture began, implying that populations should have been higher than today. That they apparently were not probably indicates that populations were limited by food availability.

The Mormon settlers came in the 1870's and by 1887, 50,000 acres were in cultivation in the Salt River Valley, 27,000 of this in small grain. Cattle raising also increased greatly with heavy overstocking in the 1880's that culminated with the disastrous drought of 1892-93 that left 50-90% of the herds dead on the ranges. Sketchy early evidence indicates that the climate of Arizona has become warmer and drier since 1900, which would favor the whitewing (Cottam and Trefethen 1968).

Phillips et al. (1964) concluded that the whitewing has approximately doubled its range in Arizona since the turn of the century. Thus, the huge colonies of whitewings near Phoenix probably began after that time. Whitewings also expanded their range into the Imperial and Coachella Valleys of California after irrigated agriculture began and after the inundation of the Salton Sea in 1907. Dense colonies were reported near Gila Bend and other areas by 1915. However, by 1925 many of the thickets had been cleared for farming and by woodcutters. By 1940, populations had declined drastically caused by the conversion of breeding habitat into agricultural fields and by overshooting (Neff 1940).

The first hunting regulations of 1916 allowed hunting from late June or early July until all whitewings had left in the fall, with a daily limit of 20 to 35 doves of all types. More mechanized agriculture and double-cropping

reduced both the brush habitat and food from grain fields by 1940, and during World War II much of the grain acreage was converted to cotton, which is of no value to doves. In 1937, the opening date of the hunting season was changed to August 7 to prevent destruction of breeding birds and orphaning of nestlings and fledglings. By the early 1940's, the whitewing population was probably only a small fraction of its former level. They probably also suffered from overshooting. In 1941, the opening date of the hunting season was changed to September 1, with a bag limit of 10-12 doves per day. Afterward, populations gradually increased to a plateau in the mid-1950's, where it remained until the 1960's with some annual fluctuations. Citrus and pecan groves then produced many birds and large areas of desert were available because of livestock watering sites (Cottam and Trefethen 1968) (Table 35).

Population estimates of whitewings have not been made in Arizona on a regular basis, but harvest estimates have been maintained by the Arizona Game and Fish Department (AZG&FD) since 1961 (Table 35). Statewide harvest increased steadily (except for a decrease in 1962) from 302,668 whitewings to 760,308 in 1968 (AZG&FD). Populations along the Gila River from Safford to San Carlos totaled 6,694 adult (14,017 adult plus young) mourning doves in 1966 (Webb 1967) (Table 31). Populations by 1970 had declined by half. The bag limit was reduced from 25 to 10 per day in 1970 and populations have now stabilized (Brown et al. 1977a). By 1973, the San Xavier and Komatke mesquite thickets, where large colonies and intense hunting occurred, were mostly dead, caused mostly by declining water tables. Since the peak in 1968, the number harvested has fallen to ca. 100,000 to 200,000/yr (mean=169,989) during the 1980's. The number of whitewings killed per trip fell during the same period from 4 to 6 in the 1960's to 1.0 to 1.4 in the 1980's; and the number of hunters decreased by half in the same period.

Table 35. White-winged dove harvest in Arizona (from Arizona Game and Fish Department annual reports).

Year	No. hunters	Avg. trips	Total harvest	Kill/ trip <sup>a/</sup>
1961	27,498	3.3	302,668	3.0
1962	29,772	2.6	145,836	1.8
1963	29,322	3.3	398,945	4.0
1964	30,467	3.2	444,176	4.1
1965	31,058	2.9	576,460	6.0
1966	37,265	2.7	620,702	5.7
1967	36,975	4.8	717,409	4.0
1968	49,503	3.5	760,308	4.3
1969	54,547	3.6	678,346	3.4
1970	46,594	3.6	419,821	2.4
1971	45,804	3.6	409,794	2.3
1972	46,677	3.6	378,379	2.2
1973	54,982	3.8	506,969	2.3
1974	55,796	3.5	438,091	2.2
1975	57,740	3.4	513,074	2.5
1976	59,425	3.6	475,096	2.1
1977	45,136	3.6	284,610	1.7
1978	47,750	3.8	344,913	1.8
1979	43,573	4.1	305,623	1.6
1980	31,942	3.3	85,971	0.7
1981	38,122	5.5	193,600	0.9
1982	32,910	3.8	139,920	1.1
1983	26,404	4.5	145,904	1.2
1984	33,011	4.3	182,763	1.3
1985	37,985	3.6	105,887	1.4
1986	39,389	3.5	203,891	1.4
1987	26,648	3.7	117,958	1.0

<sup>a/</sup> Licensed hunters only, does not include junior hunters.

Hunter participation is strongly influenced by dove populations and bag limits. In 1956, when the limit was 15 birds per day, the Arlington Station checked in 320 hunters on opening day. When the limit was raised to 25 birds in 1957, 477 hunters checked in, and in 1958 when the limit was raised to 35 whitewings plus 10 mourning doves, 992 hunters checked in. The average bag per day increased from 6 in 1951-54 to 9.85 in 1955-56, to an average 13.5 per day in 1957-65. Total kill in 1962 in the Arlington area was ca. 24% of the pre-season population, but for the entire state it was only 2.2 to 6.4% (Cottam and Trefethen 1968).

These harvest trends indicate that a serious population decline has taken place in the former dense colonies and dense feeding flocks near the colonies, that were frequented by hunters. Part of this decline has been ascribed to habitat destruction (see Sect. VI). However, personnel of the Arizona Game and Fish Department stated that available nesting habitat is presently underused. They believe the limiting factor in recent years has been food availability. Nearly all of the former grain fields have been converted to other crops, especially to cotton which has no value for doves. Mourning dove harvests in the 1980's have been ca. 10 times that of whitewings, or a mean of 1,656,519/year, Gambel quail 1,158,095 and Scaled quail 97,194/year.

We must conclude that, in Arizona, the quality of whitewing hunting has deteriorated severely in recent years. In the 1960's, the bag limit was 15 or 25 whitewings per day, the average hunter bagged 13.5 birds per day, and 760,308 were harvested per year. In 1987, the harvest was only 118,000 and the average kill per trip was only 1.0 dove.

The great feeding flocks that attracted thousands of hunters are gone. The great nesting colonies are also gone. Yet the whitewing persists in

considerable numbers in more dispersed populations and is in no danger of becoming rare. The reasons for the demise of the dense populations are many. During some years in some areas, hunters killed too many. The famous mesquite thickets where the dense colonies nested are nearly all gone---victims of declining water tables and woodcutting. Although much of the original habitat has been destroyed, saltcedar has replaced most of this; yet populations have continued to decline. Of very serious importance recently is the reduction in grain farming so that food is severely limited.

In Sinaloa (and probably also in parts of Sonora), large flocks migrate in from Arizona after August. In northern Sinaloa, populations were estimated at 2,863,000 (1,129,000 adults and 1,734,000 young). SEDUE issued 1000 hunting permits to foreigners in 1985, which could be raised to 1200 and the hunting season could be increased to cover the period mid-September to mid-March (Martinez-Lopez 1986).

Hunting regulations for the 1986-87 season were October 10-February 8 for Sinaloa and Zone 3 of Sonora and September 12-January 11 for Zone 1 of Sonora, with a limit of 20/day and possession of 90. For the 1987-88 season, this was changed to October 30-February 28 for Sinaloa and November 6-March 6 for Zones 1 and 3 of Sonora with bag/possession limits of 20/60. The number of whitewings declared by U.S. hunters reentering Arizona and New Mexico rose from 2,512 in 1979 to 22,794 in 1987, 90% of these at Nogales. Those entering through Arizona and New Mexico are only 2.1% of the total from Mexico, the rest enter through Texas (Tomlinson 1988).

11. Economic and Social Characteristics of Hunters and Hunting in Texas and Mexico.--The economics of dove hunting and the social characteristics of dove hunters for the 1975 hunting season were analyzed by Mazzaccaro (1980). The majority of the hunters (more than 95%) who hunted in Texas were from

Texas, 3.1% were from Louisiana, and the rest from 8 other states. Of hunters who hunted in Mexico, 65.6% were from Texas, 13.7% from Louisiana, 2.6% from Alabama, 2.0% from Oklahoma, and the rest from 28 other states (Mazzaccaro 1980). In 1986-87, the hunting season in Tamaulipas was August 15-October 26, with a bag/possession limit of 20/60, 25/75, and 30/90 in the three different zones. In Nuevo Leon and Coahuilla, it was August 15-November 16, with a limit of 20/60 in Nuevo Leon and 5/15 in Coahuilla. The regulations were liberalized for the 1987-88 season in Tamaulipas (August 14-November 15, 30/90 limit in all zones) and changed slightly in Nuevo Leon and Coahuilla (Tomlinson 1988). Whitewing declarations were 34% in August, 49% in September, and 16% in October (Tomlinson 1988).

Since 1979, the Office of Migratory Bird Management, USDI-Fish and Wildlife Service has summarized doves declared by U.S. hunters at U.S. ports of entry. Whitewings declared at Texas ports increased from only 17,004 in 1963 to 260,977 in 1978, and to 1,024,063 in 1987, the great majority of them (77.7% in 1987) at Brownsville and Hidalgo/McAllen; the average hunter declared 62.7 whitewings. Those entering all U.S. ports increased from 419,251 in 1979 to 1,046,857 in 1987. The total number of whitewings killed in Mexico is difficult to determine. However, Tomlinson (1988) suggested a correction factor of 3 to 4 times the number declared to compensate for those eaten in Mexico or given to the "bird boys" (young boys who retrieve the shot birds), based on interviews with returning hunters. The total kill could represent 16-22% of the estimated 19 million doves in the fall population.

Mazzaccaro (1980) concluded that a majority of the hunters in Mexico probably did not declare birds to U.S. Customs officials when they return to the U.S. Many probably gave their birds to the local citizens or the "bird retrieving boys" or ate them while in Mexico to avoid the lines at the

customs declaration stations. He reported that hunters freely admitted killing far above the legal limit in Mexico during the average two trips of 2 days each that each hunter made. The average kill in Mexico was 97 whitewings +13 mourning doves bagged, plus 13 whitewings and 2 mourning crippled, for a total of 125. The average in Texas was 15 whitewings and 19 mourning bagged plus 3 whitewing and 4 mourning crippled, for a total of 41. He calculated that 316,444 whitewings were bagged in Mexico and an additional 13% were crippled.

Mazzaccaro (1980) reported that dove hunting in northeastern Mexico and could be very expensive. Hunters who hunted in Texas spent an average \$211.58 in Texas and an additional \$50.40 in Mexico on a tourist visit during the hunting trip. Hunters who hunted in Mexico spent \$350.54 in Texas before and after the trip (arranging for guides, buying ammo, etc.) and another \$399.49 while on the hunt in Mexico (Table 36). He calculated that dove hunters contributed \$8.5 million annually to the local economy of Cameron and Hidalgo Counties in 1975. George (1988b) estimated that whitewing hunting in Texas puts ca. \$20 million into the local economy, or \$500 each for the ca. 44,000 hunters.

The social characteristics of whitewing hunters also was analyzed by Mazzaccaro (1980). The profession of 81% of those hunting in Mexico and 61% of those hunting in Texas was either professional/technical business owners or manager/foreman. The majority of those hunting in Mexico were college graduates or had advanced degrees, while the majority hunting in Texas had less education; very few, if any, of the hunters had only elementary school or less education. The incomes of hunters in Texas and Mexico (1975 salaries) was strikingly different. The mode for Texas hunters was a sharp

Table 36. Dove hunting in the Lower Rio Grande River, Texas, and in Mexico during 1975 (from Mazzaccaro 1980).

	<u>Expenditure or harvest in:</u>	
	<u>Texas</u>	<u>Mexico</u>
<u>Hunted only in Texas</u>		
Food and lodging	\$ 85.15	\$ 19.30
Ammo and equipment	38.68	
Guide	6.29	
Transportation (not personal vehicle)	17.16	
Other	<u>64.30</u>	<u>31.10</u>
TOTAL	\$211.58	\$ 50.40
<u>Hunted only in Mexico</u>		
Food and lodging	\$ 93.96	\$136.96
Guide and bird retrievers	53.57	39.48
Ammo and equipment	91.85	59.47
Transportation (not personal vehicle)	49.26	-
Hunting license		19.20
Bird stamp		48.00
Good conduct certificate		16.00
Other	<u>61.90</u>	<u>96.18</u>
TOTAL	\$350.54	\$399.49
<u>Doves harvested (entire season)</u>		
White-winged (no. per hunter)	14.8	96.9
Mourning (no. per hunter)	19.4	12.6
Number days hunted (per hunter)	2.7	4.0
Number trips (per hunter)	?	2.3
Texas residents	95%	65.6%

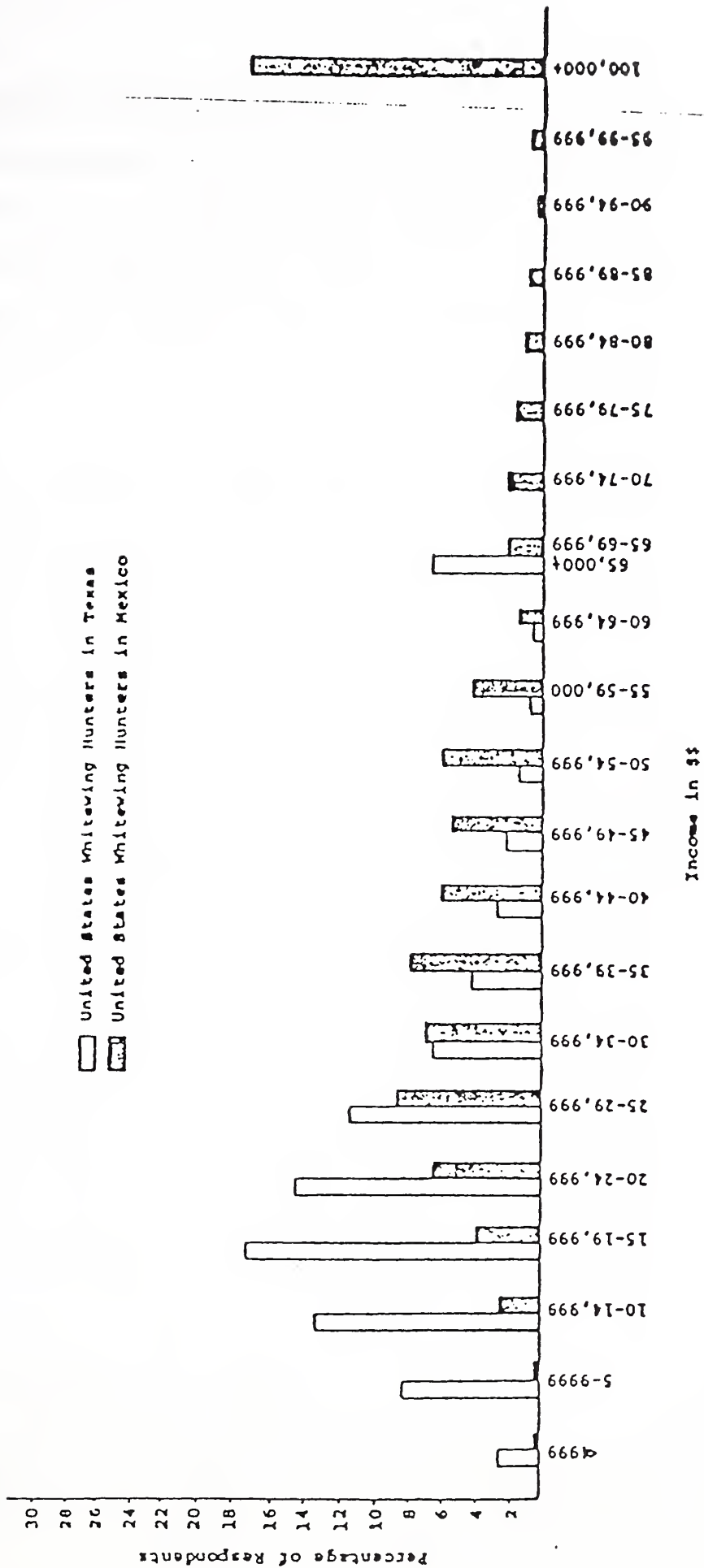


Fig. 13. Income levels of United States hunters who hunted whitewings in Texas and Mexico in 1975 (from Martinez et al. 1980).

peak at \$15,000 to \$20,000/yr with 7% reporting above \$65,000 (maximum on the questionnaire); the mode for those hunting in Mexico was a very broad peak between \$20,000 and \$60,000, but the greatest number (17%) checked the \$100,000+ category (maximum on the questionnaire) (Fig. 13). The majority of hunters were from larger towns and cities and with only a few from rural areas or small towns; a much higher percentage of those hunting in Mexico were from the larger cities.

Family members were almost twice as likely to accompany the hunting group to Texas as to Mexico. Hunters rarely traveled alone: ca. 17% traveled with one other hunter, 75% with a few other hunters, and 5.6% with a large group. Also, ca. 70% of the hunters reported that most or all of their friends off the hunting field were also hunters. Only 3.5% of the hunters in Texas and 0.7% of those in Mexico were women. Interestingly, among hunters in Texas 73.6% were married and 19.7% single, while among hunters in Mexico, 85.2% were married but only 5.8% single; this probably indicates that children were taken to Mexico much less often. The vast majority of the hunters began hunting between the ages of 6 and 15. Parents initiated 36.2% of the hunting trips to Texas and 46.9% of those to Mexico; friends initiated 42.2% of the Texas and 26.3% of the Mexican trips. Approximately 55% of the hunters had been hunting whitewing for 1-5 years, 20% for 6-10 years, 5% for 11-15 years, 4% for 16-20 years, and a few for more than 50 years.

Most hunters apparently went at their own expense, but a significant percent went as guests of friends or of a company (Mazzaccaro 1980):

	Hunted in Texas (%)	Hunted in Mexico (%)
Guest of friends	39.2	18.6
Guest of company	9.7	24.7
Not a guest	45.7	50.8
No response	5.4	5.8

Brown (1989) conducted an economic analysis on the impacts of a proposed biological control program on hunting of white-winged dove, mourning dove, and other wildlife (see Sect. VII,J of this report).

#### E. Game Birds - Mourning Dove

A large body of literature exists on the mourning dove; Fish and Wildlife Service (1961) listed 464 abstracts. However, only 25 were from Texas, 5 from Arizona, and none from new Mexico; the most notable was a study of its life history and ecology in Texas by Swank (1952). The mourning dove, Zenaida macroura, breeds throughout the 48 contiguous states of the U.S., the Greater Antilles, Mexico, and just into southern Canada. It overwinters from the southern half of the U.S. to Mexico, the Greater Antilles and Central America. Five subspecies are recognized, two in mainland North America; these are Z. m. carolinensis in the eastern third of the area, and Z. m. marginella in the western two-thirds, with an intermediate form in between. Greatest densities are through the central part of the U.S., extending into central Texas and in southern Arizona and California (Fig. 14) (Keeler et al. 1977).

The mourning dove is much more generalized in habitat and feeding requirements than is the white-winged dove. Its habitat preference is difficult to define because it is found throughout the U.S. and adapts to numerous ecological types including wood edges, shelterbelts, cities, farmlands, orchards, and many other types.

They tend to nest in isolated trees and sometimes in shade trees near dwellings. In the plains states, they nest on the ground to a considerable extent. The clearing of large areas of phreatophytes in the Southwest, the replacement of scattered croplands and mixed forests by large monocultures of pine trees in the Southeast, and the general trend toward large fields

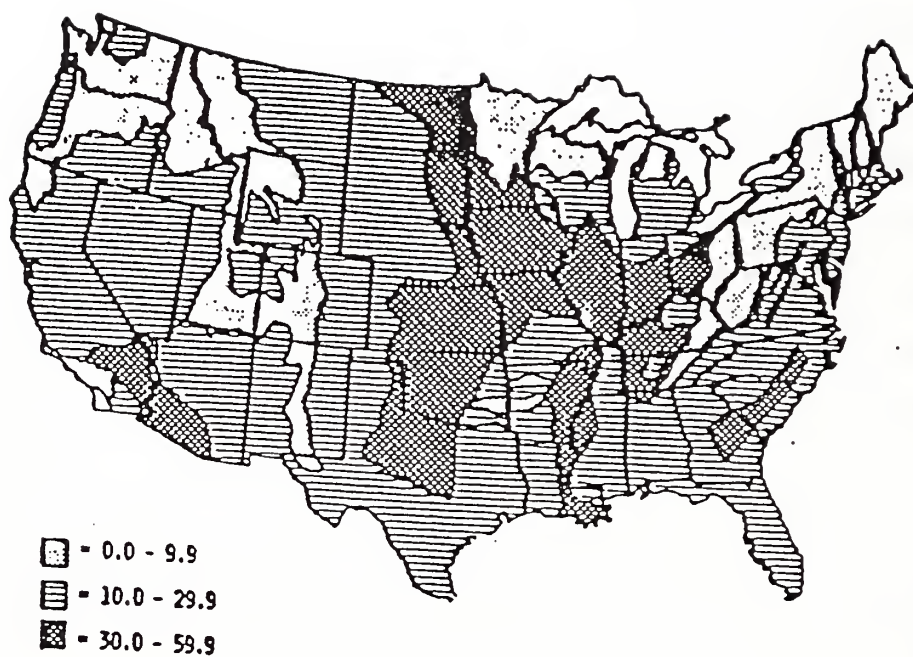


Fig. 14 Relative densities of breeding mourning doves by physiographic region, 1965-73. Mean number of doves heard calling per 70-stop call-count survey route (from Keeler et al. 1977).

and intensified agriculture are all harmful to the mourning dove (Keeler et al. 1977).

In the Buckeye-Arlington area of Arizona, mourning doves nested in mixed saltcedar-velvet mesquite while whitewings nested almost entirely in saltcedar. Mourning doves fed on weed seed and agricultural grains in a wide variety of areas and showed no preference for cultivated fields, while whitewings were almost entirely dependent on agricultural grains. Mourning dove populations remained relatively stable over the years, while whitewing populations fluctuated widely with changes in agriculture (Cunningham 1986).

Similarly, Engle-Wilson (1981), in comparing three different river systems in Arizona, found a mean density of 8.76 mourning doves per 0.4 ha in 2 areas of mesquite and 3.85 in 2 areas of saltcedar. Whitewings averaged 0.68 per 0.4 ha in the mesquite and 3.80 in saltcedar in the same areas.

In a semi-desert area near Las Cruces, NM, mourning doves fed on the following foods (Davis 1974):

	% of diet	
	<u>Summer</u>	<u>Winter</u>
Caltrop	49.0	87.0
Rockcress	14.2	trace
Tetradlea	8.7	0.5
Leafy spurge	8.2	0.5
High mallow	5.5	0.7
Toothed spurge	3.3	0.7
Spurge	1.9	0
Pigweed	1.5	4.9
Total seeds	96.1	99.9
Insects	2.8	trace

In another study in an uncultivated area in the southeastern corner of New Mexico, mourning doves fed mostly on Croton and leaf-flower, with lesser amounts on spurges, pigweed, and panic grass (Griffing and Davis 1974).

On the Lower Colorado River, populations of both mourning doves and white-winged doves were lower in saltcedar than in western honey mesquite or cottonwood-willow. Populations were 1.4 to 5.5 times greater in non-saltcedar than in saltcedar during the summer and 2.6 to 28.0 times greater in winter (Table 37).

Table 37. Average numbers of doves and quail per 100 A in three plant communities in the Lower Colorado River (from Shrader 1977, table 8).

Bird species	Saltcedar		Western honey mesquite		Cottonwood-willow	
	July	Dec.	July	Dec.	July	Dec.
White-winged dove	23.1	0	31.6	0	34.8	0
Mourning dove	34.7	1.7	118.8	15.6	47.6	0
Gambel's quail	8.1	4.3	44.5	18.5	23.7	11.4

In the same area, Anderson and Ohmart (1977b) counted all species of birds along 75 miles of transects from 1974 through 1977. By far the greatest population density of the mourning dove was in orchards, with <sup>the next four community types (well-treed cotton</sup> screwbean mesquite next, then cottonwood-willow, and <sup>juv.</sup> saltcedar and western honey mesquite <sup>about equal in fourth position</sup> (Table 38). <sup>A</sup>

On the middle Pecos River, NM, the mourning dove was the second most numerous species of bird (after the white-crowned sparrow), constituting 13.0% of the total 339,785 birds counted. It was mostly a summer resident: of the 44,286 mourning doves counted throughout the year, 49.3% were present during June-July, 30.5% during March-May, 14.6% during August-September; only 4.4% were present during October-November and 1.2% during December-February (Hildebrandt and Ohmart 1982).

*From this apparent preference for a given plant species, under certain (alt.) same height classes*

Table 38. Density of the mourning dove in various community/structural types in the Lower Colorado River Valley from May through September 1974-1977 (from Anderson and Ohmart 1977b his tables 1-1 through 1-133).

Community type	Structural type (no. per 100 acres)						Mean
	I	II	III	IV	V	VI	
Orchard	607.5	428.5	280.0	311.0			406.8
Screwbean		380.5	143.2	76.5	30.3	21.5	130.4
Cottonwood-willow	15.0	157.1	96.9	62.4	72.5	30.0	72.3
Honey-mesquite			146.0	89.8	29.0	33.3	60.0
Saltcedar	44.8	98.7	87.2	47.5	29.8	61.5	61.6
Saltcedar-honey mesquite				58.2			58.2
Desert wash				10.0		11.5	10.8
Marsh				9.9			9.9
Arrowweed						8.6	8.6
MEAN	222.4	266.2	150.7	83.2	40.4	27.7	

a/ The sampling techniques tended to underestimate dove populations, perhaps by ca. 25%. (See Sect. VII,A,2 and Fig. 10 for definition of C/S types.)

In this area, its greatest densities were in the tallest vegetation--cottonwood-willow I and II and the taller saltcedar, SC-III and IV. Densities were much lower in honey (or western honey) mesquite which was all of a low growth form (Table 39).

Near Hermosillo, Sonora, Scudday (Appendix III, this report) found 2.3 mourning dove nests/ acre, the same as the whitewings but half that of ground doves. The nests were 2-12 ft high (mean 6 ft) in saltcedar trees mostly less than 15 ft high.

Total harvest <sup>of mourning doves</sup> in the U.S. was estimated at 49 million birds annually (11.4 million recreational trips per year), which is more than for all other migratory birds combined. However, populations nationwide declined an average of 2% per year from 1963 to 1973. In the western area, populations fell by 50% from 1964 to 1971 but began increasing thereafter. Harvest in

Table 39. Density (number per 100 acres) of mourning doves in different plant community-structural types in the middle Pecos River Basin, NM and TX (Hildebrandt and Ohmart 1982, Tables 9-21).

C/S Type	Dec.- Feb.	Mar.- May	June- Jul.	Aug.- Sep.	Oct.- Nov.
Four-winged saltbush-VI	0	2	0	3	0
Cottonwood-willow-I	141	108	174	49	61
Cottonwood-willow-II	0	43	76	2	7
Saltcedar-III	1	55	102	19	0
Saltcedar-IV	0	72	125	35	7
Saltcedar-V	0	13	12	5	1
Saltcedar-VI	0	11	29	3	0
DC strips	2	30	19	31	22
Other cleared V/VI	9	9	3	13	9
Honey mesquite-V <sup>a/</sup>	3	2	0	0	1
Honey mesquite-VI <sup>a/</sup>	2	3	2	2	1
Grassy cleared-VI	1	5	2	3	6
Creosotebush-VI	0	2	0	2	3
Miscellaneous	1	9	11	7	2

<sup>a/</sup> This could be honey mesquite, western honey mesquite, or a mixture or gradation of the two; Hildebrandt and Ohmart did not distinguish between the subspecies.

each state was reported by Keeler et al. (1977), which showed twice as many harvested annually in Texas than in any other state (Table 40).

In the U.S., mourning dove hunters spent \$86.9 million out of pocket and \$137 million in income forgone (Keller et al. 1977).

In 5 southern Arizona counties, the mourning doves averaged 71.8% and white-winged doves 28.2% of the total doves harvested from 1951-59, as estimated from wing collection boxes where hunters voluntarily leave the wings of birds killed for survey purposes (AZG&FD report).

why X 1000?

Table 40. Harvest of mourning doves in the Southwest during 1972-73 (from Keeler et al. 1977, Table 9-1).

State	No. hunters X1000	Days per hunter	Harvest X1000
Arizona	63.3	5.3	1,747.4
New Mexico	24.5	5.8	500.6
Texas	318.2	3.7	7,106.0
Mexico <sup>a/</sup>	--	--	2,507.5

<sup>a/</sup> Estimated from band recoveries.

However, hunting mourning doves in northeastern Mexico is much less popular than hunting white-winged doves. From August 1987 to march 1988. U.S. hunters returning from Mexico declared the following numbers of doves (Tomlinson 1988):

	<u>Whitewings</u>	<u>Mourning</u>
Texas ports of entry	1,024,063	78,437
Arizona ports of entry	22,794	20,301

On the Pecos River, NM, the average annual mourning dove harvest for the 10 years before saltcedar clearing was 55,422. The average harvest for the 7 years after 53,950 acres were cleared was 57,916 birds, indicating no significant change in dove populations (New Mexico Department of Game and Fish 1974) (reported by Shrader 1977).

#### F. Game Birds - Gambel's Quail

Gambel's quail (Callipepla gambelii) was studied extensively on the Lower Colorado River, AZ and CA, from 1973 through 1978 (Anderson and Ohmart 1984a). Populations peaked sharply in late summer of each year, reaching densities of 40 to 65 per 100 acres. The quail hunting season opened on October 1 and populations declined by 54% by November and 71% by December, coinciding with peak hunting activity. Approximately 10% survived to breed by the following March (Fig. 15). The breeding season lasted at least six months, from February through August, longer than for any other closely related bird species. Young less than one-quarter grown were seen from mid-May through August. Anderson et al. (1982a) determined that Gambel's quail was a nonsocially regulated species and exhibited strong dispersal behavior prior to the rise in a predator population (human hunters) on October 1 and formed large coveys late in the hunting season when the number of hunters decreased markedly.

Quail densities were usually highest in velvet mesquite and lowest in cottonwood and saltcedar in all seasons. In late summer, peak densities shifted to screwbean mesquite, paralleling pod production there but still remained high in velvet mesquite (Fig. 16). Quail preferred stands that were dense but patchy, with saltbush and annuals present. Densities were highest along the interface between riparian and agricultural areas.

The preferred vegetation varied between seasons (Anderson and Ohmart 1984a). Cottonwood-willow I and II always supported low numbers of quail. They preferred areas of patchiness and high foliage density at low levels (0 to 2 ft) in summer and with screwbean mesquite trees present; they avoided areas with dense foliage in the upper levels (cottonwood willow and some saltcedar communities). In winter and spring, areas with velvet mesquite

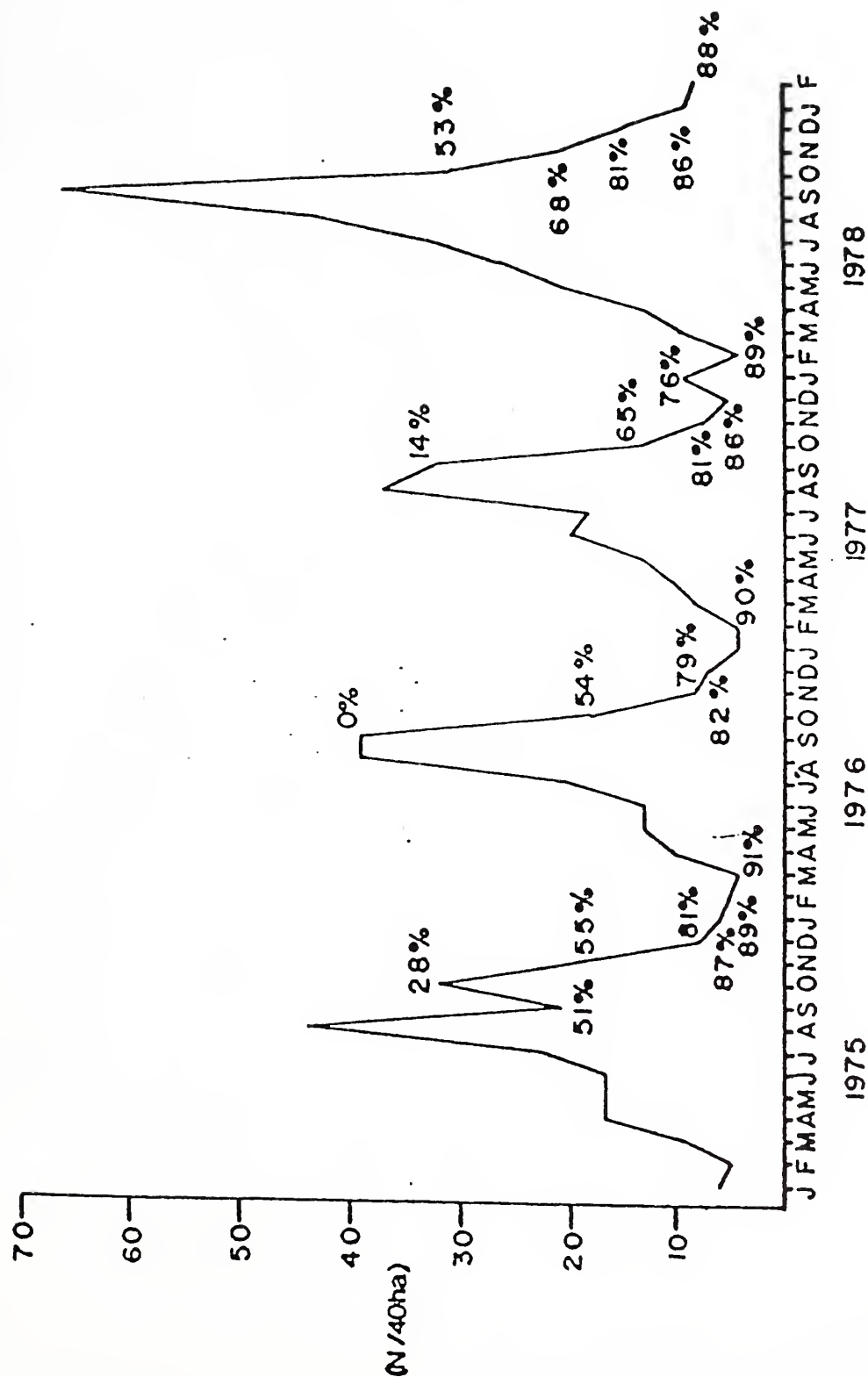
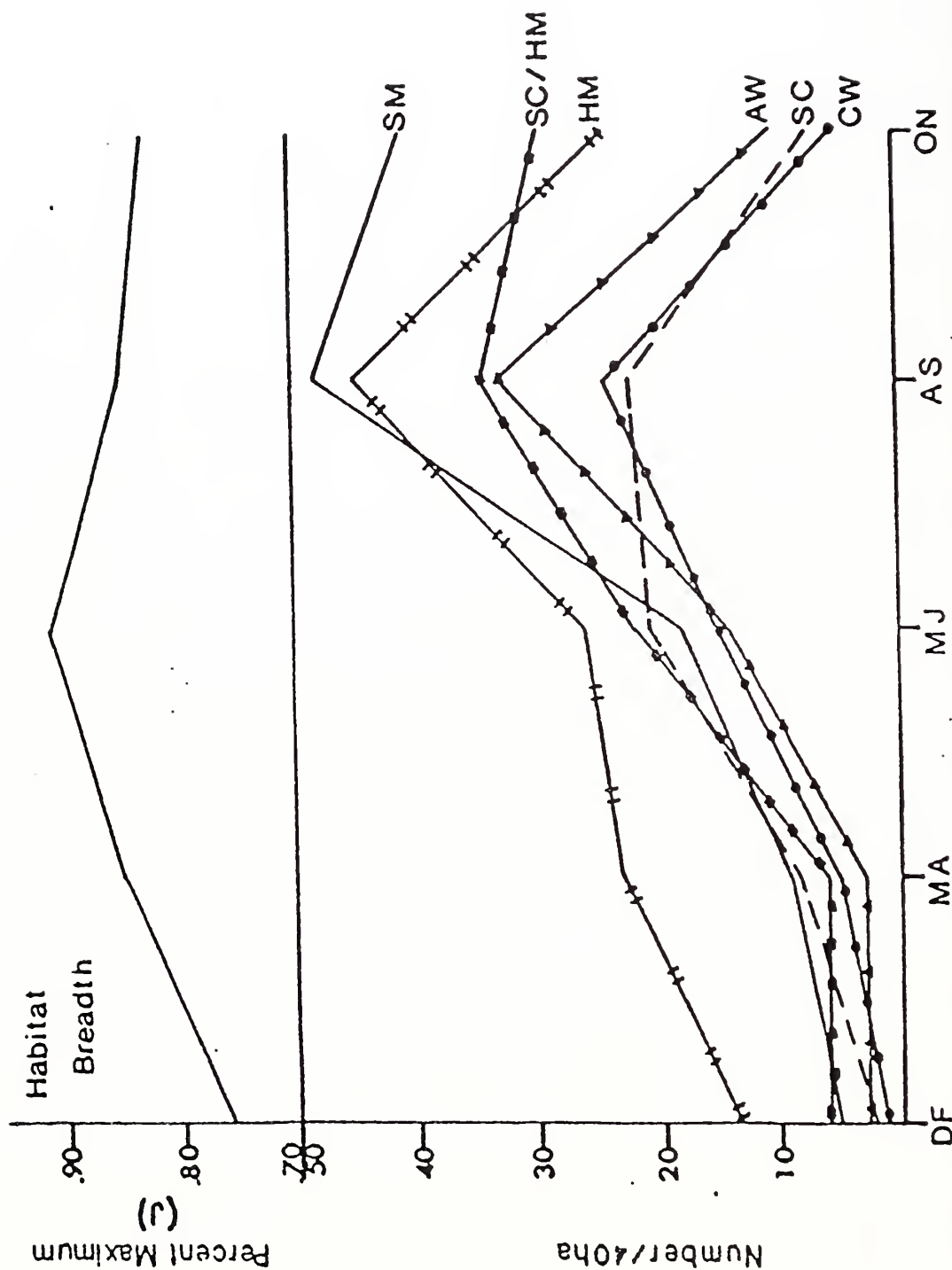


Fig. 15 Average monthly densities (N/40 ha) of Gambel's quail in all riparian vegetation in the Lower Colorado River Valley. Mortality is given as percent decrease from population peak (from Anderson and Ohmart 1984, fig. 8-2).



1975-1978

Fig. 16 Average seasonal densities (N/40 ha) in six plant communities and habitat breadth for Gambel's quail for 1975, 1978. plant communities were: SM = serowbean mesquite, SC/HM = saltcedar-honey mesquite, HM = honey mesquite, AW = arrowweed, SC = saltcedar, CW = cottonwood-willow. DF = December, January, February, MA = March, April, MJ = May, June, AS = August, September, October, November.

and shrubs were preferred. Quail overwintering in velvet mesquite and also breeding in it have an advantage by gaining experience in foraging and reduced time needed to establish breeding sites. Screwbean mesquite stands supported almost no quail during the winter. These areas lacked saltbush, had little mistletoe, and had little bare ground for production of annual plants; the presence of screwbean seed pods apparently is not enough to attract wintering quail, and the high autumn densities declined by December. Anderson and Ohmart (1984a) concluded that habitat for the Gambel's quail would be improved by converting pure saltcedar stands to mesquite or mixed communities with patchy ground cover (<10 ft. high) using quailbush and wolfberry shrubs.

Diet composition, based on examination of ca. 900 quail crops, is given in Table 41.

Year to year variation in population was best explained by food availability, which depended on the highly variable rainfall of that region.

Along the Rio Grande of western Texas, Gambel's quail had similar habitat preferences, strongly preferring thorny shrub and screwbean areas during May through July (Engle-Wilson and Ohmart 1978a, his Table 7):

<u>Plant community</u>	<u>% of total quail population</u>
Cottonwood-willow	3.7
Saltcedar	5.2
Seepwillow	0
Thorny shrub	8.1
Thorny shrub (canyons)	31.9
Screwbean mesquite	38.5
Disturbed areas	12.6

The Gambel's quail harvest in Arizona averaged 1,158,095 birds annually from 1981 through 1987 (range = 873,185 to 1,371,681), or 73% that of the

Table 41. Food selection in the field of Gambel's quail in the Lower Colorado River Valley (from Anderson and Ohmart 1984a).

Food	% frequency	% volume
Animal material (mostly insects)	29.3	8.79
Mesquite seeds	(16.3)	(24.21)
Screwbean	11.8	19.95
Velvet	4.5	4.26
Cultivated grains	12.5	26.81
Annual and other seeds	(29.88)	(33.21)
Mistletoe	3.8	8.54
Chenopodium	3.4	3.10
Panicum	1.8	4.89
Russian thistle	0.7	3.61
<u>Oligomeris</u>	2.9	2.24
Dock	2.6	0.90
Johnsongrass	1.2	0.89
Shepherd's purse	.6	1.13
85 other plant spp.	12.8	7.91
Plant material	8.6	7.15

mourning dove harvest and 7.2 times that of the white-winged dove harvest. An average of 74,799 hunters made an average of 5.1 trips each and killed an average 2.3 quails per trip (AZG&FD 1988).

#### G. Other Game Animals and Birds

Several other species of big game and small game mammals and birds are important in the southwest. Some of these, such as the beaver, muskrat, raccoon, porcupine, skunks, ducks, geese, and sandhill crane are dependent in riparian areas and the others are facultative users of these areas. Also, nearly all of the trapping of furbearers probably takes place in riparian

areas. On the Rio Grande of western Texas, Engle-Wilson and Ohmart (1978) counted animals along 39 transects in different community types; large mammals were counted from a fixed-wing aircraft at 150-200 ft above the ground for 6 hours a day in December and February. Based on the acres of each community type surveyed, 51.2% of all animals were in cottonwood-willow, 29.4% in thorny shrub and 9.2% in saltcedar (additional animals were counted on the rocky hillsides (pediment) at the edge of the valley (Table 42).

On the Pecos River, NM, Hildebrandt and Ohmart (1982) counted 337 animals along 50 transects totalling 2,986 acres (animals observed, heard, or tracks seen were included). Based on acres of each community type surveyed, 36.6% were in cottonwood-willow, 21.5% in saltcedar, 12.2% in grassy cleared acres, 9.2% in honey mesquite, and 20.5% in other areas (Table <sup>42</sup>~~40~~). Of the 67 animals found in other areas, 35 were mule deer that were mostly in edges between two habitat types and 22 were coyotes also mostly in edge zones. The honey mesquite probably had many fewer animals than normal because in this area, it was of the atypical growth form of shrubby mats <sup>20 x 50 ft</sup> 50-60 ft diam. less than 3 ft high.

In both these areas, it appeared that cottonwood-willow was preferred by most large mammals. Thorny shrubs (nearly all mesquite with some bare ground and grasses) was also strongly preferred to saltcedar on the Rio Grande. On the Pecos, saltcedar was preferred over the mat-form of honey mesquite.

In Arizona, the number of hunters and the annual harvest of different game species indicate that hunting is a very important outdoor recreation for many people. The same is probably true for New Mexico, western Texas and other western states where saltcedar has invaded. Habitat preferences demonstrated on the Rio Grande and Pecos rivers indicate that the riparian

Table 42. Habitat preference and harvest of other game animals.

	Habitat preference <sup>a/</sup>								Other	Hunters Ariz. <sup>d/</sup>	Har- vest <sup>e/</sup>
	Rio Grande, TX <sup>b/</sup>				Pecos River <sup>c/</sup>						
	CW	SC	TS	P	CW	SC	HM	GC			
Antelope							1	1		1,179	
Badger			4				1				
Bear											
Beaver	1				5						
Bobcat		2				4			1		5,
Buffalo										46	
Cottontail										36,692	311,
Coyote			7	2	22	30	20	27	22		12,
Deer:											
mule		1	5	10	18	59	3	35	35	{ 83,460 }	17,
whitetail											
Elk										9,959	3,
Fox, gray			1	2		1					20,
Lion											
Muskrat						1			2		
Peccary		2	13							29,567	7,
Porcupine	5	1		1	7	4					
Raccoon		3	1		3	10			5		
Ringtailed											
cat			2	1	1						3,
Sheep,											
bighorn										62	
Skunk:											
hog-nosed			4	2		1					} 2,
striped	10	8	9			10	2		1		
Squirrel:											
rock			3	5							
tree										18,396	125,
Weasel						2		2	1		
No. active											
trappers	16	16	37	11	16	33	4	2	10	1,064	

Table 42. (continued).

	Habitat preference <sup>a/</sup>								Other	Hunters Ariz. <sup>d/</sup>	Harvest Ariz. <sup>d/</sup>
	Rio Grande, TX <sup>b/</sup>				Pecos River <sup>c/</sup>						
	CW	SC	TS	P	CW	SC	HM	GC			
Total counted	16	17	49	23	56	122	27	65	67		
No. species	3	6	10	7	6	10	5	4	7		
Acres sampled	99	686	559	?	244	901	464	856	521		
No./100 A	17.2	3.1	9.8	--	23.0	13.5	5.8	7.6	12.9		
%/unit area	51.2	9.2	29.4	--	36.6	21.5	9.2	12.1	20.5		

<sup>a/</sup> CW=cottonwood-willow, SC=saltcedar, TS=thorny shrub, P=pediment, HM=honey mesquite, GC=grassy cleared area.

<sup>b/</sup> From Engle-Wilson and Ohmart (1978a, his Table 14).

<sup>c/</sup> From Hildebrandt and Ohmart (1982, his Table 38).

<sup>d/</sup> From AZG&FD (1988).

<sup>e/</sup> Number trapped.

ecosystem and the quality of hunting has been substantially degraded by the replacement of native vegetation by the invading saltcedar.

Waterfowl are obligately dependent on aquatic and riparian areas for breeding and for varying degrees also for feeding. Populations of ducks and geese have fallen alarmingly in recent years. Compared with the average annual population during the 1960's, average populations for the last 5 years (1983-87) are only from 2.8 to 34.0% as high for various types (AZG&FD 1988) (Table 43). The major cause of this decline in waterfowl populations in the central United States is probably loss of habitat in the Canadian breeding grounds. However, most Arizona waterfowl breed more in the Great Basin area than in Canada, and drastic losses in habitat have not occurred there. Populations in Arizona fluctuate considerably depending on rainfall. During wet years, more waterfowl remain in the expanded wet areas; and during dry years, more fly on to other areas. Part of the change in populations seen

between the 1960's and the 1980's (Table 43) is due to a change in sampling techniques. During 1989-1990, another real decline has occurred because of dry weather (Phil Smith, AZG&FD, pers. comm., June 1990). Habitat degradation in the Southwest, caused by saltcedar invasion and man-caused changes, is also a contributing factor. No studies were found that related saltcedar or other plant community types to waterfowl success. However, very dense growth of saltcedar along the water edge is known to interfere with the birds leaving the water to feed.

Again, harvest records and numbers of hunters in Arizona indicate that "duck hunting" is an important outdoor recreation (Table 43), as it probably also is in other southwestern areas invaded by saltcedar.

Near Hermosillo, Sonora, Scudday (Appendix III, this report) found ground dove populations in saltcedar of 4.7 nests/acre, or twice that of white-winged and mourning doves. The ground dove nests averaged 4 ft (range 2-6 ft) above the ground, which was lowest of the 3 dove species. They trapped only one cotton rat in 120 trap nights, saw one desert spiny lizard and no other mammals in the saltcedar, although many dogs and a few feral house cats were seen.

#### H. Fishes

Arizona hosts 32 and New Mexico 59 species of native fishes, for a total of 75 species. Six of these are endangered and one threatened on the federal list; in addition, 30 species are state listed as endangered within New Mexico. The major threat to the survival of these species is habitat degradation, including lowering water tables, dams, diversions, vegetation clearing, pollution, grazing, and the introduction of exotics (Hubbard 1977). Effects of habitat modification are increased water temperatures, reduced streamside vegetation from grazing and other factors harmful to fish. The

Table 43. Waterfowl and other game bird populations and harvest in Arizona (from AZG&FD 1988, January waterfowl survey).

	Population survey			Hunters 1983-87	Harvest 1983-87
	Mean 1960-69	Mean 1983-87	% 1983-87 of 1960's		
Ducks	26,160	8,905	34.0		
Mergansers	4,969	1,428	28.7		
Coots	<u>24,380</u>	<u>770</u>	<u>2.8</u>		
Total ducks	55,509	11,103	20.0		87,581
Canada geese <sup>a/</sup>	5,250	1,745	33.2		
Snow geese	<u>432</u>	<u>18</u>	<u>4.2</u>		
Total geese	5,682	1,763	31.0		4,831
Total				10,494	
Pheasant				64	23
Blue grouse				726	652
Bandtail pigeon				626	1,096
Sandhill crane				132	123

<sup>a/</sup> Interior Arizona only, not including the Colorado River area. Canada geese on the lower Colorado total ca. 22,000 at Cibola, 1600 at Havasu and 2000 at Imperial, for a state total of ca. 27,000 (Phil Smith, AZG&FD, pers. comm., June 1990).

fishes of the Rio Grande between El Paso and the Pecos River confluence were inventoried by Hubbs et al. (1977), who discuss factors affecting the ecology of the system.

In some cases grazing is harmful to fish. In Rock Creek, Montana, only 63 lb/acre of brown trout was produced in a heavily grazed area while 213 lb was produced in an ungrazed area (Kennedy 1977). In a 100-ft section of a stream, 31 steelhead were produced in a heavily grazed area and 75 in a lightly grazed area. In Wisconsin, insects provided only 5% of the annual diet of brown trout where cattle grazed freely but 15% where there was no

grazing. The effect of grazing on the welfare of fish in the Southwest has not been investigated.

No information was found relating saltcedar to habitat quality for fishes, although the increased silting, narrowing and blockage of channels must have a profound effect in some areas.

#### I. Drinking Water for Wildlife

A major harmful effect of saltcedar on wildlife is that it probably causes springs and small streams to dry up during periods of drought. This would deprive wildlife of drinking water, causing these areas to be abandoned by the wildlife capable of traveling to other watering sites and causing the death of those unable to reach other sites. Unfortunately, little information was found in the literature to document this situation although it is of potentially major importance in some areas, and it has been documented for the endangered peninsular bighorn sheep in southern California (Comrack 1988). <sup>2 on 6-7</sup> Rowlands (1989) recently documented one such case in Death Valley National Monument. In this case, <sup>^</sup>athel had become established at formerly permanent springs, causing them to dry up and to be abandoned by wildlife. After the athel was cut and the <sup>stumps</sup> killed, the springs began flowing again and the wildlife returned. Such situations may be common on desert areas and on small tributary streams, greatly reducing the range occupied by wildlife. Saltcedar infestation around many desert drinking holes has occurred in many of the southwestern parks (see Sect. <sup>VI</sup> ~~IV~~, E, 2, this report). <sup>pg 91</sup>

#### J. Impacts of Biocontrol on Wildlife

As shown above, many species of wildlife are adversely affected by the replacement of the native vegetation by saltcedar. The effects are caused by a reduction in plant diversity, by the reduction in favored plant species,

by the fact that saltcedar ~~itself~~ offers little or no food as well as unfavorable shelter, by reducing drinking water supplies and for other reasons. Biological control would be expected to reduce saltcedar and to produce a return of the original vegetation (see Sect. IV,F, this report). If this occurs, wildlife populations would be expected to increase as the more favorable habitat returns.

Wildlife values do not lend themselves easily to economic analyses. However, Brown (1989) was able to analyze the economic effects of biological control on dove hunting. For other wildlife species, he performed a qualitative analysis by rating types of impacts on each species as positive or negative rather than assigning economic values.

1. White-winged Dove and Mourning Dove Hunting.--Brown (1989) conducted an economic analysis of the projected losses to white-winged dove populations, hunting and expenditures on hunting if saltcedar were controlled biologically. He estimated that only 7.5% of the habitat in Arizona and 40.0% in west Texas was available for whitewing nesting because of the absence of nearby agricultural fields, that 41% of the hunting on the lower Colorado and 74% of that on the Gila-Salt Rivers, AZ, was in saltcedar habitat, that in Texas the number of hunters equalled the 45,000 white-winged dove stamps sold and that each hunter made 3.1 trips per year, and that Arizona residents spent \$39.00/trip and that Texas and New Mexico residents spent \$41.50/trip for hunting either type of dove. Brown (1989) then estimated that a 50% effective biocontrol program would reduce annual expenditures for white-winged dove hunting by \$200,000 in Texas and by \$500,000 in Arizona. A 90% effective program would reduce annual expenditures by \$300,000 in Texas and \$1,100,000 in Arizona (Table 44). These estimates assume no replacement of saltcedar. If the native vegetation,

especially mesquite, returned as the saltcedar declined, or if successful revegetation projects were carried out, these losses would be reduced or would disappear.

Table 44. Economic losses to white-winged dove hunting expected from biological control of saltcedar (from Brown 1989).

	White-winged dove		
	Texas	Ariz.	Calif.
<u>Dove population</u>			
Total	1,000,000	1,540,000	?
In saltcedar	165,581	315,000	?
<u>Doves harvested</u>			
Total	300,000	175,000	?
In saltcedar	16,583	98,000	5,000
<u>Dove hunters in saltcedar habitats</u>			
Number trips (days)	23,715	70,660	1,000
Expenditures	\$998,115	\$2,838,420	\$52,000
<u>Projected losses associated with biocontrol of saltcedar</u>			
50% control	\$200,000	\$ 500,000	
90% control	\$300,000	\$1,100,000	

Brown (1989) concluded that the mourning dove would not be affected significantly by a biological control program for saltcedar because of the doves easy adaptability to many types of environments (Table 45).

2. Wildlife Ecological Values.—Brown (1989) concluded that a 50% effective biological control program for saltcedar would have little or no effect on any common wildlife species, not even the white-winged dove since it is presently under-utilizing saltcedar nesting habitat. However, a 90% effective biological control program would have a beneficial effect on most common wildlife species, except for the white-winged dove which would be harmed by this level of control. Some other species that appear to favor saltcedar at present probably would also be favored by a more diverse plant

Table 45. Economic losses to mourning dove hunting expected from biological control of saltcedar (from Brown 1989).

	Mourning dove		
	Texas	Ariz.	N.Mex.
<u>Dove population</u>			
Total	50 million	Sev. million	Few
In saltcedar	154,000	2,310,000	20,000 <sup>a/</sup>
<u>Doves harvested</u>			
Total	5-7 million	1,613,600	334,000
In saltcedar	15,000	451,800	20,000
<u>Dove hunters in saltcedar habitats</u>			
Number trips (days)	1,116	53,550	1,488
Expenditures	\$46,314	\$2,088,450	\$61,752
<u>Projected losses associated with biocontrol of saltcedar</u>			
50% control	NS	NS	
90% control	NS	NS	

<sup>a/</sup> Population unknown, 20,000 used as a lower limit.

community. For example, the white-crowned sparrow is by far the most abundant bird in saltcedar on the middle Pecos River during the winter but it uses saltcedar only for shelter while feeding in nearby areas. It would probably use native trees and shrubs equally well if they replaced saltcedar.

Brown (1989), through published state and federal lists, found that 2 species of reptiles, 1 mammal, and 35 species and subspecies of birds are endangered, threatened or are under consideration as such in saltcedar-infested areas of California, Arizona, New Mexico, and Texas. With a 50% effective biological control program, no species would be adversely affected but only the peninsular bighorn sheep would benefit. Saltcedar has dried up or reduced the flow at several drinking water sources for the bighorn sheep in southern California (Comrack 1988). With a 90% effective biological control program, Brown (1989) concluded that 13 species of birds would

benefit and 3 species (the yellow-billed cuckoo, the Mississippi kite and the willow flycatcher) would be adversely affected, and the other species would be unaffected. The yellow-billed cuckoo forages and nests in saltcedar along the Rio Grande and Pecos rivers but not in California and Arizona where it nests in cottonwood-willow. The Mississippi kite heavily utilizes the Apache cicada (that is most abundant in saltcedar) to feed its nestlings; however, this usage occurs only during a very brief period (see Sect. XV, A, this report). The willow flycatcher nests primarily in saltcedar along the Colorado River in the Grand Canyon.

The two quantitative aspects of wildlife impacts that Brown (1989) was able to address were costs of revegetating native riparian habitat (see Sect. IV,D,2,e, this report) and non-consumptive values (birdwatching, etc.) (see Sect. VII,C of this report). Economic impacts of saltcedar on non-consumptive wildlife usage are discussed in Sect. VII,C.

## VIII. USE OF WATER BY SALT CEDAR

### A. Introduction

The overriding impetus for control of saltcedar until the 1970's was the prospect of salvaging groundwater or water from streams for off-site agricultural, municipal or industrial usage. This was a prospect of great interest in the semi-arid southwest where agricultural and economic development is strongly influenced by water availability. A number of large, long-term and expensive studies were done by teams of highly qualified researchers to measure water usage and potential salvage. Because of the great importance of water usage to the overall saltcedar problem, this research is reported in detail here.

1. Historical Perspective. The availability and quality of water for human domestic and agricultural use in semi-arid southwestern North America have been major problems for a long time. Traces of ancient canals indicate that extensive agricultural irrigation systems were developed by the Indians of this area hundreds of years ago. During the 1800's, settlers from the United States cleared the river bottoms for firewood and farming. Large irrigation projects in the late 1800's and early 1900's altered the water regime along the rivers and, consequently, the vegetation growing on the flood plains and created water shortages that became critical during the dry years of the 1920's (Horton and Campbell 1974, Horton 1976). The great immigration and increase in human population since that time have further increased the demand for water for domestic, municipal, agricultural, and industrial uses.

A great concern developed that phreatophytic vegetation growing along the streams and on the floodplains used great amounts of water that

otherwise would be available for human use. (The term "phreatophyte" was first used by Meinzer in 1923 to distinguish plants that habitually grow with their roots in the water table or to the capillary fringe above it and thus can obtain a perennially secure water supply (Meinzer 1927, van Hylckama 1980c). This concern was intensified by the dramatic invasion and spread of saltcedar in the river floodplains during the 1930's.

From the 1920's and through the 1960's, an ever increasing effort went into evaluating <sup>human?</sup> water needs, constructing reservoirs and channels, estimating water losses caused by phreatophytic plants, and in clearing these plants from river floodplains. *this section not germane & needed*

2. Politico-Administrative Agreements. Compacts were formed between states for the development of water resources and as the basis for subdivision and distribution of the water in a shared river basin.

a. Lower Colorado River Basin.--The Lower Colorado River Compact included the Colorado River Basin south of Lee's Ferry (just south of the Utah-Arizona line) and includes the Gila River Basin and nearly all of Arizona and parts of southern California, Nevada, Utah, western New Mexico, and northern Sonora, Mexico (Blaney and Harris 1952).

b. Pecos River Basin.--The history of irrigation on the Pecos River of New Mexico and Texas was outlined by Blaney et al. (1942b) and Johnson et al. (1955). Scobey (1942) reported that in 1940 the Pecos River Basin contained 210,200 A of irrigated crops and 454,370 A in "native vegetation," including 239,360 A in brush and saltcedar. Johnson et al. (1955) reported that the Middle Pecos River Basin was infested with 38,820 A of saltcedar. They did not give acreages in the Lower Basin (from the NM-TX state line to the Rio Grande) but estimated that 60% of the water released from the Red Bluff Reservoir was lost. The Carlsbad Irrigation project had

responsibility for the irrigation of 25,000 acres of agricultural land below Lake McMillan. The Pecos River Joint Investigation began in 1939 with the cooperation of Federal and State agencies, led by the National Resources Planning Board. The results of the studies on water salvage and phreatophyte control were reviewed by Blaney et al. (1942b), Elmendorf et al. (1951), Robinson (1964), Horton (1976), and Weeks et al. (1987).

In 1965, the Carlsbad Irrigation District could divert only 44,000 A ft of water for the 25,055 A of irrigated farmland under its jurisdiction below Lake McMillan--which was only one-third of the amount needed. Downstream, the Red Bluff Irrigation District also had insufficient water, farmers were drilling wells and the water table was falling seriously. The Bureau of Reclamation (1966) proposed clearing 70,000 A of phreatophytes (mostly saltcedar) from which they calculated that 2.18 A/ft/A of water could be salvaged, for a total of 152,600 A ft salvaged for agricultural usage at a cost of \$2.5 million.

c. Research and control planning and coordination.--To oversee and conduct research, clearing and channeling operations, committees and councils were formed, such as the Salt Cedar Interagency Council and the Salt Cedar Interagency Task Force for New Mexico.

The need for wider coordination was presented to the Pacific Southwest Federal Inter-Agency Technical Committee (PSFIATC) (which changed its name to the Pacific Southwest Inter-Agency Committee (PSIAC) in 1955). PSFIATC formed the Phreatophyte Subcommittee which held its first meeting in January 1951. The Subcommittee met four times annually for the next 20 years (through 1970). Member organizations included the Geological Survey and Bureau of Reclamation of the USDI; Soil Conservation Service, Forest Service, and Bureau of Plant Industry of the USDA; and Corps of Engineers of the U.S.

Department of the Army. Later members included the Agricultural Research Service, Bureau of Indian Affairs, Fish and Wildlife Service, Weather Bureau, Bureau of Land Management, International Boundary and Water Commission and various agencies of the states of Utah, Nevada, California, Wyoming, Colorado, Arizona, and New Mexico (PSIAC 1966a, b; 1970). Activities of the committee were concentrated on: 1) water losses caused by phreatophytes, 2) the amount of water that could be saved by clearing, and 3) control methods aimed at complete elimination.

By the late 1960's, interests had shifted to other possible values of phreatophytes and ways to develop compromise management systems including recreation, wildlife and other resources. Clearing operations were interrupted during the 1970's because of opposition from environmentalist groups to the destruction of wildlife habitat, probably also combined with the inability of the researchers to demonstrate substantial amounts of water "salvaged" for downstream use.

The Subcommittee was reorganized as the Vegetation Management Technical Committee, which held its first meeting in March 1971. The new objectives were to stimulate programs on water quality and quantity in managing vegetation in all life zones, with benefits and detriments considered for all environmental resources affected; also, to provide information to federal and state agencies and to maintain liaison with others concerned with vegetation management (Horton 1976).

#### B. Methodology of Measuring Water Usage by Phreatophytic Plants

Johns (1989) discussed three basic methodologies for measuring evapotranspiration by plants: 1) mass-transport (flux-gradient and eddy correlation), 2) mass-balance, including hydrologic (watershed) and soil water (lysimetry and soil-water profiles), and 3) energy-balance methods

may have to, because of data limitations,

(Bowen-ratio, radiation, and temperature models). He pointed out that we must rely on simplified procedures, that may result in sizable errors, because we do not know enough about the complexities of the controlling factors to permit more adequate calculations. Van Hylckama (1980a,b) arranged the measurement methodologies into two basic categories--hydrologic (or water budget) and meteorologic. Among the hydrologic methods, lysimeter (or evapotranspirometer) tanks measure usage by individual (or a few) plants. The inflow-outflow, transpiration well, seepage run, slope seepage, and chloride increase methods measure usage over a large area in the field, usually without distinction between plant species or other vegetation characteristics. All of these <sup>what methods?</sup> methods require large-scale, time-consuming, expensive experimental procedures. The more direct methods are by using lysimeter tanks (but this method contains various sources of error and the data <sup>maybe</sup> are difficult to extrapolate to large areas) or by inflow-outflow measurements of watersheds, or river reaches (which contain large measurement errors relative to residual amount used by the vegetation).

In order to overcome these disadvantages, great effort has been made to develop empirical equations based on readily available climatic data that would predict water usage and, during the 1970's, to <sup>apply</sup> develop micrometeorological methods that estimate water output by the plant rather than water input to the plant. These micrometeorological methods estimate the movement of water vapor across the leaf-surface:air boundary and in the area within and surrounding the plant canopy. The required parameters <sup>include such elements as</sup> are air temperature and humidity in gradients above the plant, soil temperature, solar radiation, wind speed and air movement through the plants, and transpiration from the leaf surface. In theory, recorders can be set up in an area and within a few months water usage can be determined. In practice, this has

would be useful.

proven to be more difficult (van Hlyckama 1980a). ~~These methods beg for a~~ <sup>often</sup> standard of comparison for calibration, which logically would be the direct methods except that these contain their own errors.

Most of the research using soil water and hydrologic methods has been centered in a few large stations in the Lower Colorado River Basin, the Rio Grande Basin, and the Pecos River Basin (the status of these and other phreatophyte research projects was reviewed by Robinson (1964) and Johns (1989)):

1) The Glenbar Station located near Safford, AZ, with a study area along a 46-mile reach of the Gila River, was established by the USDI, Bureau of Reclamation and the Geological Survey (USDI) in 1940, with major additions in 1943 (Gatewood et al. 1950).

2) The Buckeye Station was established on the Gila River, 25 miles southwest of Phoenix, AZ, in 1959, also by the Bureau of Reclamation and Geological Survey (Robinson and Bowser 1959).

3) The Gila River Phreatophyte Project was established along a 15-mile reach of the river upstream from the San Carlos Reservoir in 1962 (the upper portion overlapped that of the Glenbar study area) by the U.S. Geological Survey (Culler 1965, Culler et al. 1970).

4) The Wellton-Mohawk Area on the Gila River near Yuma, AZ, was primarily a vegetation clearing project begun in 1958 by the Bureau of Reclamation, Corps of Engineers and the University of Arizona (Frost and Hamilton 1960).

5) A small site on the Salt River (a tributary of the Gila) near Phoenix, AZ, was established in 1960 (Gary 1962).

6) On the Colorado River, research was done at a site 20 miles north of Yuma, AZ, in 1961 by the U.S. Geological Survey and the Bureau of Reclamation (McDonald and Hughes 1968).

7) Research was also done on the Colorado River at a site 31 miles south of Blythe, CA, and Ehrenburg, AZ, during the 1960's and 1970's (Bur. Reclam. 1964, Gay and Sammis 1977).

These stations were established by cooperative efforts of the U.S. Department of the Interior's Bureau of Reclamation and Geological Survey. Lysimeter tanks were installed at Glenbar, Buckeye, 20 miles north of Yuma, and at

Winnemucca, NV; but only those at Glenbar and Buckeye were used extensively for saltcedar. Extensive studies on large floodplain areas, using the inflow-outflow method, were done at Glenbar and by the Gila River Phreatophyte Project near San Carlos, AZ.

Johns (1989) listed 98 basic research studies that measured use of water by naturally occurring vegetation, 14 of which measured usage by saltcedar.

Johns (1990) pointed out that certain water use quantities have become <sup>well known</sup> associated with certain areas, for example the Lower Colorado River area. These were based on improperly interpreted early experiments in other areas of differing usage quantities and used equations with inadequate data for certain terms and which ignored other important factors. These quantities then became fixed in the literature and were cited by later workers and used in the calculation of various studies upon which were based important decisions on river management. These estimates may have overall credibility but should be used with caution.

Johns (1989) also prepared an abstract bibliography of 307 references pertaining to water usage by vegetation in the 17 conterminous western states of the U.S., but including a few pertinent ones from Canada and the eastern U.S. Among these were the following bibliographic reports summarizing research:

Robinson 1959	Sopper 1971
United States Senate 1960	Horton 1973
Robinson and Johnson 1961	Paylore 1974
Robinson 1964	Affleck 1975
Chow 1964	Bur. Reclamation 1979
Christiansen and Low 1970	Branson et al. 1981

### C. Measurements in Lysimeter or Evapotranspiration Tanks

Lysimeter tanks (or evapotranspiration tanks or potometers) of various types have been extensively used for many years to measure water use by

individual (or a few) plants (Muckel 1966); this is a type of "water budget" method. The first tanks were small and simple. As researchers gained experience, they discovered many factors that influenced the data and how to construct tanks that gave more reliable results. Finally, large tanks (1000 sq ft surface area by 14 ft deep) with instrumentation for precise control of water level, for flushing, and other controls were constructed. Gatewood et al. (1950) noted that, theoretically, this method could be used in any area of phreatophytes but practically it is not applicable to large trees or to areas with a water table deeper than a few feet below the surface. *then weigh*

Plants are grown in a watertight tank, usually buried to the soil level and, preferably, surrounded by vegetation similar to that under study. Water is added periodically to replace that used by the plant and the amount is recorded. Water use is the amount added (including rainfall) divided by the surface area of the tank, less the amount lost from the soil surface by evaporation (usually determined in adjacent tanks with no vegetation). The tanks can be equipped to maintain a desired depth of water table, salinity levels, for periodic flushing, etc. *3 ylv*

At the 1961-4 meeting, the Phreatophyte Subcommittee (PSIAC 1966b), reported that 42 tanks were then in operation to measure water use: 6 at Buckeye, AZ; 9 at Imperial Dam, CA; 6 at Mittry Lake, CA; and 21 new ones at Winnemucca, NV (the latter described by Robinson 1962). Another site at Yuma, AZ, studied arrowweed, saltbush and bermudagrass (McDonald and Hughes 1968). Robinson (1964) reviewed 7 projects where lysimeter tanks were in use but only the Buckeye, AZ, station was studying saltcedar; he did not review the Carlsbad and Glenbar projects. The sites at Glenbar and Buckeye, AZ, and at Carlsbad and Bernardo, NM, contained saltcedar.

The problems encountered in these lysimeter tank studies and the interpretation of the results were discussed by Weeks et al. (1987) and Johns (1990). Horton (1976) observed that ". . . these tank data, in spite of their weaknesses and perhaps inaccuracies, are the most detailed that are available on water losses from saltcedar and certain associated species."

1. Early Studies in California. As early as 1911, Lee (1912) in Owens Valley, CA, estimated evapotranspiration by using tanks with willow, saltgrass and with water tables at various depths. Studies started in southern California in 1927 by the USDA-Bureau of Agricultural Engineering and the California Division of Water Resources measured consumptive use of water by willow, saltgrass, bermudagrass and cattails in lysimeter tanks. Water use increased greatly as depth to the water table decreased and could be equal to or greater than evapotranspiration from a nearby Weather Bureau pan. Also, vegetation in tanks exposed to full sun and wind (the "oasis effect") used up to 3 times as much water as that in tanks surrounded by a dense cover of the same species (Blaney 1933, Young and Blaney 1942). Water use by willow in these tanks was 53 in. per year, which they adjusted to 47.8 in. for application to large areas. Johns (1990) points out that both of these figures should be used with caution. Blaney and Ewing (1946), in the Salinas and San Luis Valleys of California, calculated that natural vegetation (mixed stands of cottonwood, willow, baccharis and grasses) used 36 in. of groundwater annually with a 4-7 ft water table and 21 in. with a 6-10 ft water table; usage by tules (Scirpus spp.) in lysimeter tanks varied from 57 to 60 in. from 1941-1943. Water use by willow in these tanks was 53 in. per year, which they adjusted to 47.8 in. for application to large areas.

2. Pecos River near Carlsbad, NM. Blaney et al. (1942a, their Table 99) at Carlsbad, NM, measured an average 4.8 ft of water usage by

saltcedar in small tanks at 2 ft and 4 ft water tables. Then, using the empirical equations of Blaney and Morin (1942), they estimated water usage by saltcedar in 1940 at 7 sites from Las Vegas, NM, to Fort Stockton, TX. Usage near the river increased from 4.3 ft at Las Vegas to 6.0 ft from Carlsbad to Fort Stockton; sites away from the river were estimated to use from 2.9 ft at Las Vegas to 4.0 ft from Carlsbad to Fort Stockton (their Table 104). They estimated total consumptive use by "native vegetation" (their Table 125) as:

Upper basin	29,734 A ft/yr
Middle basin	388,538 A ft/yr
Lower basin	<u>356,668 A ft/yr</u>
Total	774,940 A ft/yr

tanks were  
"unrepresentative"

These tanks were not well buffered from wind and sun from the sides, were small and contained only one shrub each (Horton and Campbell 1974). Horton (1976) concluded that these tank measurements were invalid because the treatments were not replicated and the test was run for only one year, which did not allow sufficient time for development of the shrubs in the tanks.

3. Gila River near Safford, AZ. The first studies in the Safford area were in 1940 by the U.S. Geological Survey which established tanks planted to saltcedar and seepwillow (Baccharis glutinosa=B. salicifolia) (Turner and Halpenny 1941). Water usage by saltcedar <sup>was</sup> 47.9 in. at a 4-ft water table and 61.2 in. with a 2-ft water table. Baccharis used 31.2 and 52.0 in. at 2- and 4-ft water tables, and evaporation from bare soil at a 2-ft water table was 39.7 in. Johns (1990) considers these values questionable because the plants were small, density was unknown, and the tanks were surrounded by bare soil.

A larger station was established near Glenbar by the Phelps Dodge Corp. in 1943. The Glenbar station was located in a saltcedar thicket and contained 18 lysimeter tanks 4 ft diam. and from 3-1/2 to 8 ft deep; 7 tanks, 6 ft diam. and 6 to 10 ft deep; 4 tanks, 10 ft diam. and 8 or 10 ft deep; and a weather station. Experiments were conducted during 1943 and 1944 (Gatewood et al. 1950). Unfortunately, this study was terminated by flooding at the end of the second summer. *not clear*

Water use in the tanks depended on depth to the water table, size and density of the plants, salinity of the water, temperature, and humidity. After converting plant canopy diameter and height to "100% volume-density," they calculated that saltcedar in 6 and 10 ft diam. lysimeter tanks used the following amounts of water:

<u>Water table depth (ft)</u>	<u>Water used by saltcedar (ft)</u>	<u>Evaporation from bare soil (ft)</u>
2		3.0, 1.8
3		1.8
4	9.17	0.1
6	8.4	
6.7	7.4	

The usage by saltcedar was 50 to 80% more than that used by Baccharis at the same water table levels (Fig. 17). However, Baccharis was able to grow at a shallower water table (2 ft) where it used more water than saltcedar.

In the field, average depth of the water table where saltcedar grew was 7 ft and Gatewood et al. (1950) used 7.35 ft as the estimated water use. The 46-mile reach of the Gila River bottom contained 2,786 acres of saltcedar (at 100% volume-density) which they calculated used 27,550 acre ft of ground-water per year (Table 46).

Annual 7

Table 46. Total water usage by phreatophytes on the Gila River, AZ, based on six methods of calculation (from Gatewood et al. 1950, his Tables 58, 59).

Reach	Vegetation at 100% vol-density		Draft on ground water (acre feet) (not including precipitation)					Total (including precip.)
	Acres	% salt-cedar	Lysimeter tanks	Transpiration well	Seepage-run	Inflow-outflow	Chloride increase	Slope-seepage
Thatcher - Glenbar	1,324	71.0	9,070	6,740	8,590	-- a/	6,020	6,680
Glenbar - Ft. Thomas	1,078	84.2	7,420	5,900	6,500	5,180	5,220	4,630
Ft. Thomas - Black Pt.	957	49.0	5,060	3,940	5,970	5,880	3,590	3,790
Black Pt. - Calva	1,361	34.5	6,000	4,850	4,990	4,290	-- a/	-- a/
Thatcher - Calva	4,720		27,550	21,430	26,050	-- a/	-- a/	-- a/
% ± of average <sup>b/</sup>			19.10 +18.7	-7.410 -6.4	+12.576 +18.6	-7.818 +5.2	-8,225.1 -16.2	-8,225.1 -19.9
Approx. ft use incl. precipitation			5.84	4.54	5.52	4.52	4.50	4.50
								6.01

a/ Not computed.  
b/ Based on reaches 2 and 3, Glenbar-Ft. Thomas and Ft. Thomas-Black Pt.

avg 4,903.3 ft

don't  
match  
Table 4

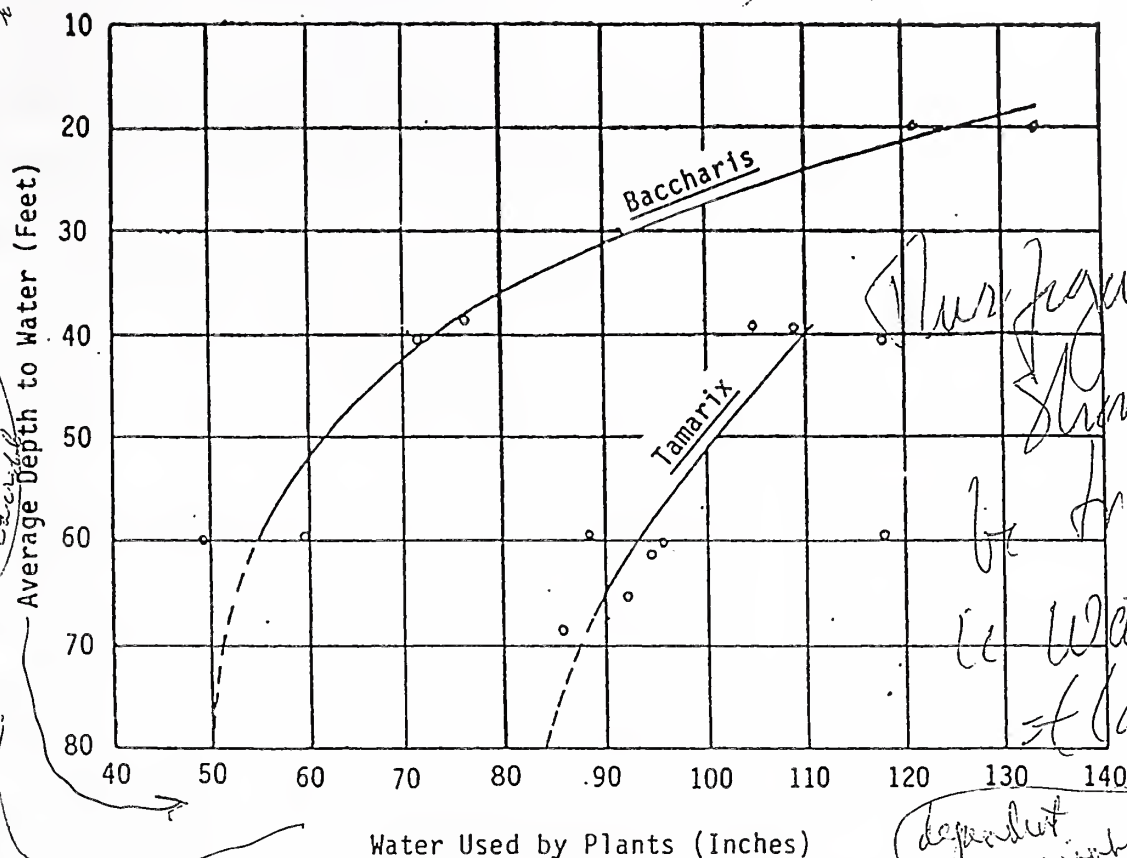


Fig. 17 Relation between depth to water and water used by plants in tanks October 1, 1943, to September 22, 1944 (from Gatewood et al. 1950 Fig. 39).

In the Safford Valley, new growth appeared about April 1 and the fronds persisted until frost. Appreciable transpiration began when the monthly mean maximum temperature reached 70°F and increased each month until maximum usage of 21 to 24 in. per month was reached in June, July and August, then declined through November (Gatewood et al. 1950) (Fig. 18).

Gatewood et al. (1950) discussed in detail the factors that might influence the reliability of data from lysimeter tanks. Changes in soil temperature were small, occurred slowly, and they concluded had only a small effect on the water table. However, changes in air temperature were sometimes great and rapid. For example, a passing cold front in April caused a temperature drop of 19°F in 20 min., causing a sharp drop in the water level in all tanks with recorders and also in a nearby transpiration well. When heat was

TSN drives, primarily  
by RADIATION NOT Temp

why did  $\downarrow T_a$  drop water level?

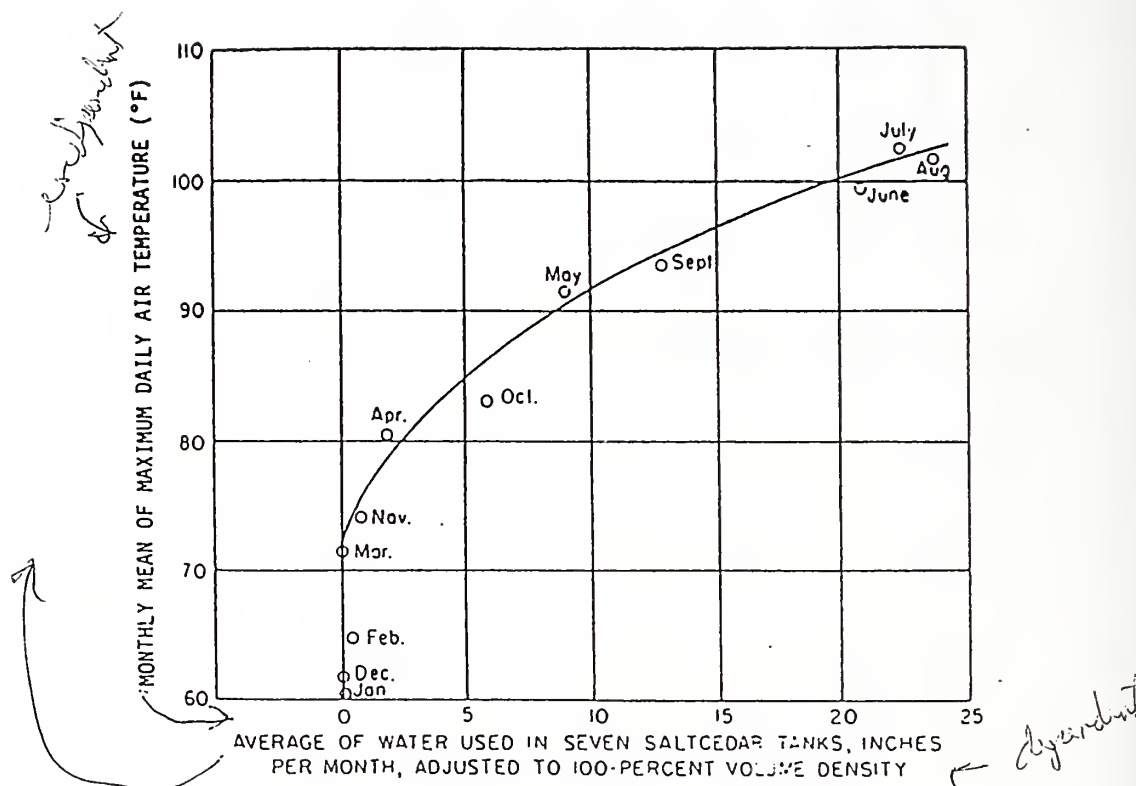


Fig. 18 Relation between maximum temperature and transpiration by saltcedar, October 1, 1943, to September 22, 1944 (from Gatewood et al. 1950, Fig. 36).

applied experimentally (hot rocks laid on top of the tank and covered) the water level rose sharply then gradually declined; both effects were without explanation. Transpiration by saltcedar did not occur below an air temperature of 73°F, but above this threshold it was closely correlated with temperature. They could not detect a relationship between relative humidity and rate of transpiration. However, rainfall quickly raised the water level in the tanks if the soil was coarse and the water table shallow.

Changes in the water level were closely correlated with changes in barometric pressure in tanks with fine material but not in tanks with coarse material. Water of lower mineral content was added to the tanks so that salt accumulation was slight. Depth to the water table had a strong effect on usage.

The calculations by Gatewood et al. (1950) of water usage probably over-estimated the amount used by saltcedar partly because their conversion to 100% volume-density assumes a linear relationship between the two. However, subsequent tests by van Hylckama (1974) showed that when half of the plants in a tank were removed, the water use was reduced by only 10 percent. Perhaps the amount of water actually used in the tanks of Gatewood et al. (1950) would be a more realistic estimate of use in the field than the amount after conversion to 100% volume-density (an assumption also made by Johns 1990). In that case, usage would be as in Table 47. After considering possible sources of errors, Gatewood et al. (1950) concluded that extrapolation of the results could cause major errors in estimated usage and the fact that their test trees were younger than the average field plant could cause medium errors but that other factors would cause only minor errors.

Table 47. Water use for selected depths and densities, Glenbar tanks (from Gatewood et al. 1950, his Fig. 39, Tables 26 and 28).

Tank number	Water depth (feet/tank)	Volume density (%)	Water use <sup>a</sup> (feet/tank)
15	4.00	84.0	6.50
16	4.10	100.0	7.60
Average	4.05		7.05
12	5.90	90.0	6.90
17	6.00	86.8	5.30
18	6.00	88.2	4.70
Average	5.97		5.63
20	6.50	75.2	5.10
19	6.80	78.2	4.70
Average	6.65		4.90

a/ less rainfall.

Horton and Campbell (1974) pointed out that the measurements of Gatewood et al. (1950) during the first year are similar to those at Carlsbad, NM, on

the Pecos River during 1939-40. However, during the second year, growth was vigorous and water losses were probably higher than typical saltcedar. This, together with faulty extrapolation based on the "100% volume-density" factor, led to maximum estimates of 9.2 ft <sup>yr</sup> and an average of 7.35 ft. These figures were cited in the literature for many years, contributing to many published overestimates of water usage (Horton 1976, Johns 1990).

#### 4. Gila River near Buckeye, AZ

a. Facilities.--The second major research station where saltcedar was tested in lysimeters was the Buckeye site, on the Gila River floodplain 30 mi west of Phoenix, AZ. The site was established in 1959, with 6 large, plastic-lined evapotranspirometer tanks: 4 tanks 30x30 ft and 14 ft deep and 2 tanks 33x33 ft and 12 ft deep; 25 saltcedar plants 4 to 6 ft tall were transplanted to each tank (Robinson and Bowser 1959). In late 1962, 5 more tanks were constructed, each 20x20 ft and 6 ft deep (van Hylckama 1968b, 1974). Research at this site was reported by T.E.A. van Hylckama of the U.S. Geological Survey in a series of papers from 1960 to 1980. <sup>(van Hylckama 1974)</sup> At Buckeye, research was intended to determine if either of two fast and easy indirect methods, the energy-budget and the mass-transfer methods (the Blaney-Criddle and Jensen-Haise methods), could substitute satisfactorily for the slow, expensive direct water-budget method that used evapotranspirometer tanks (van Hylckama 1960).

The evapotranspirometer tanks were designed to measure the effect of depth to the water table on the amount of water used by saltcedar. Experiments to measure the effect of salinity of the groundwater (discovered after the experiments began) were superimposed on the depth tests. Results were not published until the third growing season, by which time the plants were beginning to exhibit a growth pattern typical of mature plants.

b. Water usage.--Maximum water use recorded in the lysimeter tanks for an entire year at Buckeye was 311 cm (10.2 ft) in Tank 3 in 1965, at a 1.5 m water table after the saline water was flushed from the tank before the growing season began. Tank 4 (at a 2.1 m water table) also had a very high usage of 260 cm (8.5 ft) in 1965. Uses of 200 cm (6.5 ft) or more/year were measured on several occasions; however, in half of the tanks, water use was less than 150 cm (4.9 ft)/year.

Ground water was maintained at 3 different levels from 1960 to 1965: Tanks 3 and 5 at 1.5 m (5 ft), Tanks 1 and 4 at 2.1 m (7 ft) and Tanks 2 and 6 at 2.7 m (9 ft), 2 tanks at each depth (van Hylckama 1970a, 1974). Water use during 1961, 1962 and 1963 averaged 215.6 cm (7.07 ft) per year in the two 1.5 m tanks, 149.4 cm (4.90 ft) in the 2.1 m tanks, and 96.6 cm (3.17 ft) in the 2.7 m tanks. During this time, water use declined by 16% from 106 cm/yr to 89 cm in the 2.7 m tank but increased by 14% and 13% in the 1.5 and 2.1 m tanks (van Hylckama 1970a, 1974). The increase at the shallow water tables was probably caused by increasing plant size, while the decrease in the 2.7 m tank was probably caused by increasing salt concentration in the groundwater.

c. Effects of salinity on water usage.--After the 1963 season, van Hylckama (1968a, 1970a) discovered that the salinity of the water in the tanks had increased greatly; sodium had increased from less than 750 to more than 1200 ppm and chloride from less than 1600 to more than 2100 ppm. The tanks with the lowest water table had the greatest salt accumulation because they contained less water. All the tanks were flushed out in early 1964 to reduce the electrical conductivity (measured in millimho/cm at 25°C) from  $EC_{e31}$  to  $EC_{e5}$  or less which resulted in increased water usage of 44% in the 1.5 m tanks, 80% in the 2.2 m tanks, and 188% in the 2.7 m tanks during

1964. However, van Hylckama (1968a, 1970a) considered this data invalid because the tanks were flooded by overflow from nearby Waterman Wash.

At the beginning of 1965, after building a levee to prevent flooding, half of the tanks (1 at each water table depth) were again flushed and half were not flushed. During 1965, water usage was again less in the unflushed tanks: 27% less in the 1.5 m tanks, 36% less in the 2.1 m tanks, and 56% less in the 2.7 m tanks. Water usage also decreased when the water table was deeper, by 20% at the 2.1 m depth and by 36% at the 2.7 m depth (Table 48) (van Hylckama 1968a, 1974):

Table 48. *Continued* Evapotranspiration in cm and (ft) from 30x30 ft lysimeters planted to saltcedar at Buckeye, AZ, 1965 (from van Hylckama 1974, his Table 7).

Flushing	Depth to water table in meters and (feet)			
	1.5 (4.9)	2.1 (6.9)	2.7 (8.9)	Mean
Flushed	310.8 (10.2)	259.8 (8.5)	238.0 (7.8)	269.6 (8.8)
Not flushed	<u>225.8 (7.4)</u>	<u>167.5 (5.5)</u>	<u>105.6 (3.5)</u>	<u>166.3 (5.5)</u>
Mean	268.3 (8.8)	213.7 (7.01)	171.8 (5.04)	218.0 (7.2)

Van Hylckama (1974) found that water usage declined linearly from ca. 280 mm (9.2 ft)/yr at  $EC_e 10$  to ca. 100 cm (3.3 ft)/yr at  $EC_e 35$  (Figs. 19, 20). Several of the data points differ substantially in graphs for 1965 data published by van Hylckama (1968a, his Fig. 4) and van Hylckama (1974, his Fig. 35); we must assume that the latter are correct. His 1966 data from these tanks is discussed below in the section "Plant density."

In somewhat risky extrapolation of these *data*, van Hylckama (1968a) suggested that saltcedar might use ca. 10.5 <sup>cm</sup> ft/yr if the water were fresh; also, no water would be used at a conductivity of ca.  $EC_e 58$ , which is within the range (40-70) of the topsoil under saltcedar where seeds do not germinate.

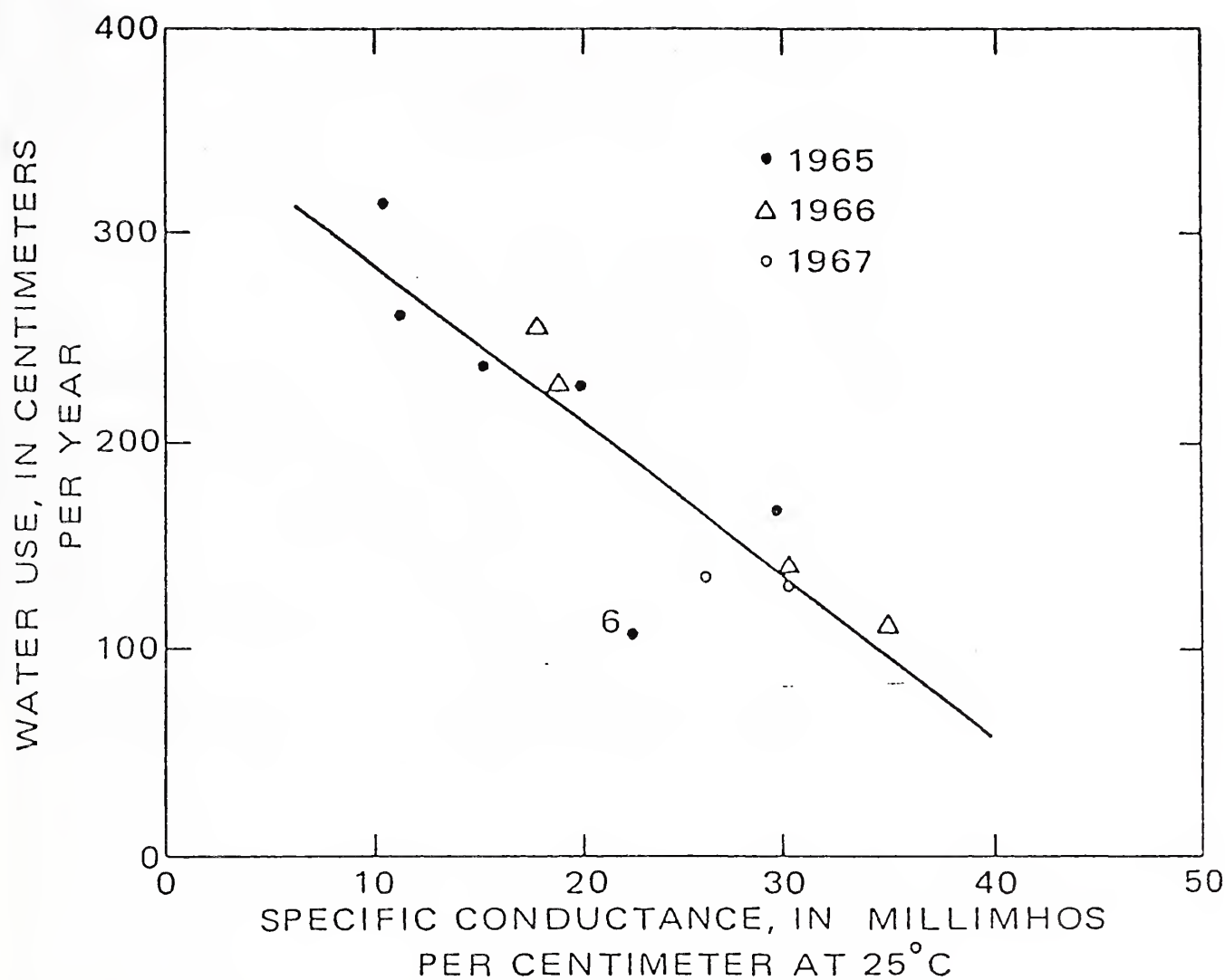


Fig. 19 Total water use per year in six evapotranspirometers versus specific conductance of the saturation extract of soil samples taken from the root zones in July or August of each year. The number 6 refers to an anomalous datum for Tank 6 in 1965 (from van Hylckama 1974, his Fig. 36).

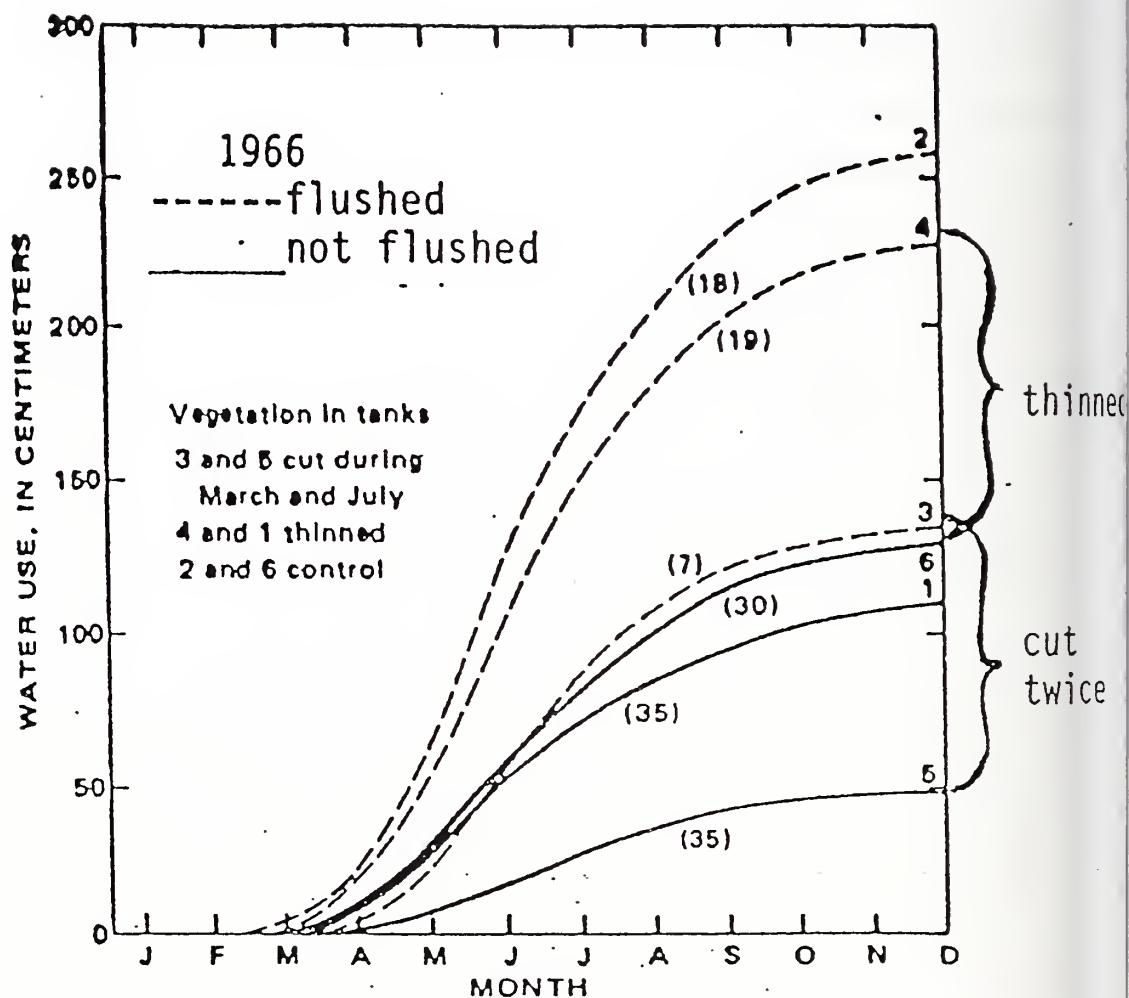


Fig. 20 Accumulated water use in six evapotranspirometers (numbers shown at right on curves) during 1966 showing the effects of density of stand and salinity of artificially maintained ground water. Dashed curves represent tanks flushed in Jan. 1966; solid curves represent tanks not flushed. Numbers in parenthesis give the specific conductance ( $\text{mmho cm}^{-1}$  at  $25^\circ\text{C}$ ) of the soil moisture extract in the root zones as determined from samples taken in August (from van Hylckama 1974, his Fig. 16).

The results in these 6 large tanks were extended and corroborated in another experiment in a pair of smaller tanks (20x20 ft x 6 ft deep). One was watered with the project water used for all the experiments ( $EC_e=7.57$ ) and the other was watered with much "fresher" water from a nearby farmer's well ( $EC_e=3.64$ ). The saltcedar watered with project water used 170 cm (5.6 ft) from June 1963 through March 1964 while the tank watered with fresh water used 264 cm (8.6 ft); also, growth was much more vigorous in the fresh water tank (van Hylckama 1974).

d. Effects of plant density.--At the Buckeye Station, van Hylckama (1970a, 1974) determined the effect of thinning and cutting on water usage by saltcedar; this test was superimposed on the treatments of salinity (Fig. 20). The vegetation in Tanks 1 and 4 was thinned to ca. 50% of original density by cutting off half the branches in each tank. In Tanks 3 and 5, all vegetation was cut off at knee height. All tanks were maintained at a 2.1 m water table during 1966 for these tests.

The tanks thinned to 50% foliage density used only 10-15% less water than the control tanks. Previous workers had commonly used a volume-density correction factor to calculate water usage. This could cause two types of errors: 1) if water use was known at 50% density, a prediction of loss by this stand when it developed to 100% density would overestimate water usage by almost 50%; 2) if use was known at 100% density, reducing the estimate by one-half of this amount for stands of 50% density would greatly underestimate actual usage (van Hylckama 1970a, 1974).

The plants cut knee high in March used much less water than the uncut plants. Within 2 months, water use had increased greatly with regrowth; the trees were again cut in mid-July and water use again dropped. During the

year, these plants used much less water than the control in both the flushed or the unflushed treatments (Fig. 20).

Regrowth occurred very rapidly when the trees were cut off (Table 49). On individual branches, terminal growth of more than 50 mm per day was observed; in one tank, growth averaged 25 mm per day on all branches on 10 trees over a 78-day period in the spring. Growth probably reached 4 mm per hour during peak periods (van Hylckama 1970a, 1974).

The experiments on depth to water table, <sup>which</sup> salinity of the groundwater and density of foliage all demonstrated that saltcedar does not always transpire at its potential rate. Van Hylckama (1970a) concluded that when saltcedar grows in nature above a water table often as deep as 4 m, it probably uses much less than its potential. Estimates that do not consider this are likely to considerably overestimate the amount of water that can be "saved" by saltcedar control.

Table 49. Twig growth of saltcedar April to June '66 (from van Hylckama 1970a (his Table 4) and 1974)<sup>a/</sup>.

	Mean growth per tree (mm) <sup>a/</sup>				
	In six lysimeter tanks			Outside tanks	
	No treat	Thinned to 50%	Cut off	Non-irrigated	Sprinkle irrigated
Flushed	464	792	1967	--	--
Not flushed	259	289	800	125	448

<sup>a/</sup> Mean of 10 trees, all twigs on each tree measured.

e. Diurnal and seasonal fluctuations. -- In tanks with saltcedar, evapotranspiration reached a peak of ca. 36 liters/hr in early afternoon during late June from a low of ca. 12 liters/hr just after midnight. In tanks with no vegetation, two peaks of ca. 3 liters/hr were seen: one about

need surface area  
of tank to interpret  
ET

why  $CO_2$  in water action?

228

6:00 a.m. and one about 7:00 p.m.; the first caused by evaporation and the second by recharge of the soil above the water table (van Hylckama 1966, 1974).

Van Hylckama (1969) also observed that growth and development of saltcedar declined sharply at the beginning of each July, although earlier in the year these had been very high. Carbon dioxide flux was closely related to the rate of water use by the plants and the flux (reflecting the indicating rate of photosynthesis) dipped sharply each afternoon.  $CO_2$  fluxes above and within a saltcedar thicket varied from ca. 370 ppm at midnight to 290 at mid-day, but this was insufficient to account for the observed differences in photosynthesis; air movement during the day prevented  $CO_2$  concentration from reaching high levels.  $CO_2$  flux showed a strong depression at air temperatures above 35-40°C. *ppm is not a flux unit!!*

Van Hylckama (1969) concluded that saltcedar is so temperature sensitive that its water use is reduced on hot afternoons, caused by stomatal closure. *must you not peak in afternoon on p. 227*

He could find no completely satisfactory explanation for the change in ground-water level in bare-soil ET tanks that paralleled changes in barometric pressure of the atmosphere. Expansion of entrapped air bubbles seemed too small to account for the observed effects but expansion of the outside soil pressing on the plastic liners of the tanks could be a possibility (van Hylckama 1968b). In vegetated tanks, diurnal fluctuations of water level lagged barometric pressure by 4 hours, probably because the plants first used soil moisture before they started pumping ground water. *table* *see pg 256 Fig 2*

Van Hylckama (1974) concluded that 1) water use varied with many factors and 2) plastic-lined evapotranspirometers may be capricious instruments yielding data that should be considered with caution. He concluded that both the Blaney-Criddle and the Jensen-Haise models under-predicted saltcedar

evapotranspiration. However, Johns (1990) stated that the tank measurements may be too high to be representative of surrounding conditions and should be used with caution.

5. Rio Grande, near Bernardo, NM.

a. Early studies.--Blaney et al. (1938) reported results of tank experiments with crops and native vegetation at 4 locations in the Upper Rio Grande Basin of New Mexico and Texas. From these data, they estimated that in the Upper Rio Grande Basin, 737,199 A of "native vegetation" used an average of 1.43 A ft of water, or 1,056,174 A ft/year from San Carlos to Val, CO. <sup>annual</sup>

During the 1950's, the states of Colorado and New Mexico began considering how to salvage water by control of phreatophytes, land drainage, and river channeling to alleviate their extreme debit status under the Rio Grande Compact. Investigations began to determine the location, type and density of the vegetation, the amount of water consumed, and the amount of water that could be salvaged by vegetation control (Bur. Reclam. 1972).

Studies during the 1950's using the inflow-outflow method were not precise enough to make comparisons and transpiration wells and evapotranspiration tanks were installed. A prototype study was initiated near Bernardo to compare cleared vs. uncleared conditions on 14,136 acres; the clearing of 6,258 acres was completed in July 1964 and the study was completed in 1966. Erratic results were obtained from the well data (using a modification of the equation of White 1932) and measurements were made in the lysimeter tanks as a comparison. Results were again erratic, varying from twice to half the amounts recorded in the tanks, indicating that the method was unreliable, and probably was influenced by many factors such as temperature, atmospheric

pressure, RH, height of the water table, and porosity of the soil (Bur. Reclam. 1972).

b. Large lysimeter studies: 1960's.--In 1961, 9 large lysimeter tanks were constructed on the saltcedar-infested floodplain near Bernardo at an elevation of 4,728 ft. Each tank was 12 ft deep and 31.6 ft square, with a surface area of 1000 sq ft. Six tanks were planted to saltcedar (100 plants per tank) and 3 were maintained with bare soil. The experimental design and operation are described by Bur. Reclam. (1972). Experiments were conducted from April 1962 through 1968 to measure: 1) water use by saltcedar, 2) effects of changing depth of the water table, 3) effects of clearing on water use, 4) to compare water use with that in other areas, and 5) to provide a value for the "C" factor (a correction factor for vegetation that does not have a complete dormant period) in the transpiration well formula (Bur. Reclam. 1972).

Consumptive use in the 6 tanks for the 7 years averaged  $0.97 \text{ m}$   $3.18 \text{ ft/yr}$  and ranged from  $0.701$   $1.250$   $2.84$   $0.865$  ft in different tanks across all years and from  $1.125$  to  $3.69 \text{ ft}$  in different years for all tanks (Table 50).

During the first 8 months of 1962, the water table in all tanks was maintained at 2.5 ft to establish the shrubs; the treatment levels of 3 or 5 ft were established in September.

However, the effect of depth to water table was not consistent. Water use in Tank 4 (constant 5 ft water table) was consistently more than that in Tank 3 (constant 3 ft water table). Usage in Tank 2 (3 ft) and Tank 5 (5 ft) was similar; however, when the water table level in these two tanks was switched after 5 years, water use continued in the same pattern for the next two years in spite of the change in depth (Figs. 21, 22). The use-to-depth relationship may have been influenced by spacing of the plants in the tanks

Table 50. Consumptive use of water by saltcedar at Bernardo, NM (in feet, precipitation and change in soil moisture included) (from Bur. Reclam. 1972).

Tank No.	Depth to water table <sup>a/</sup>	Year							Mean
		1962	1963	1964	1965	1966	1967	1968	
1	var.	3.20	3.33	3.16	2.99	2.76	3.04	3.39	3.12
2	3-5	2.57	3.36	2.93	2.10	2.22	2.02	1.38	2.37
3	3	2.62	3.55	3.18	2.32	2.56	2.16	1.97	2.62
4	5	2.79	3.86	3.67	2.97	3.05	3.01	3.22	3.22
5	5-3	2.80	4.42	4.70	4.15	4.49	4.02	4.07	4.09
6	var.-5	3.15	3.62	4.44	3.70	3.84	3.48	3.37	3.66
Total		17.12	22.14	22.08	18.24	18.91	17.74	17.39	
Mean		2.85	3.69	3.68	3.04	3.15	2.96	2.90	3.18

<sup>a/</sup> Depths in Tanks 2, 5 and 6 changed after 5 years; Tanks 1 and 6 were at variable depths.

and root development during a critical time in the life of the plants. Salinity probably was not a factor because the tanks were flushed as needed to keep salinity at a minimum (Bur. Reclam. 1972). These studies probably demonstrated that a 3 ft water table is too shallow for optimum growth of saltcedar.

Evaporation from the bare-soil tanks decreased uniformly with greater depth to the water (with some variation between tanks); evaporation at the 1 ft water table was 1-1/2 to 2 ft and at the 2 ft depth was ca. 1-1/2 ft. Evaporation at the 5 ft depth was less than 6 in. and at the 8 ft depth was almost none.

Research at both the Glenbar station in Safford Valley, AZ, and at Buckeye sites showed a consistent relationship between depth to water table and water use; however, the data at Bernardo were inconsistent (Bur. Reclam. 1972). This might be because of an unfortunate selection of depths--if a

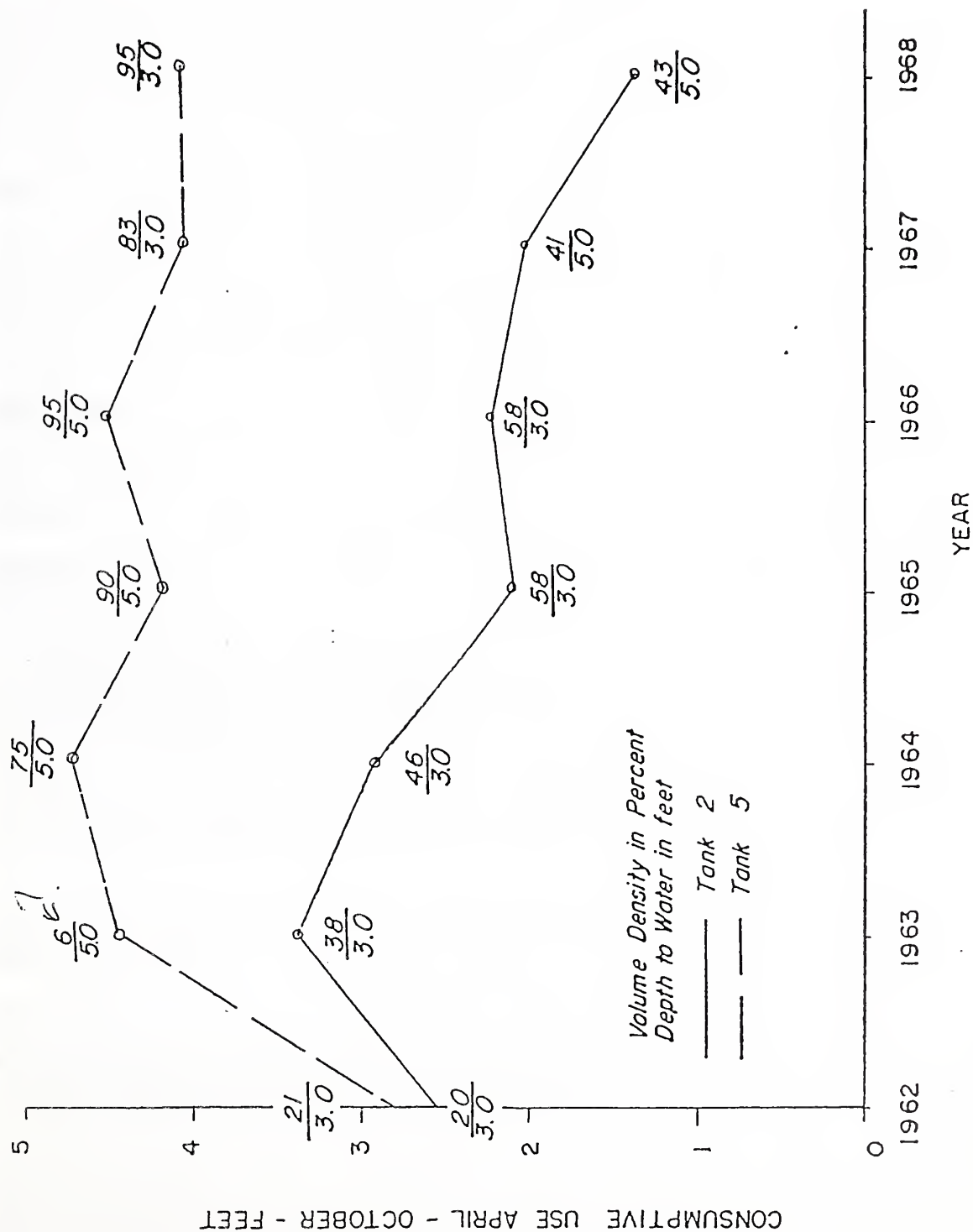


Fig. 21 Effects of changing the depth of the water table on use of water by saltcedar in two lysimeter tanks at Bernardo, NM (from Bur. Reclam. 1972) (at each point, top number = volume density in percent, bottom number = depth to water table in feet).

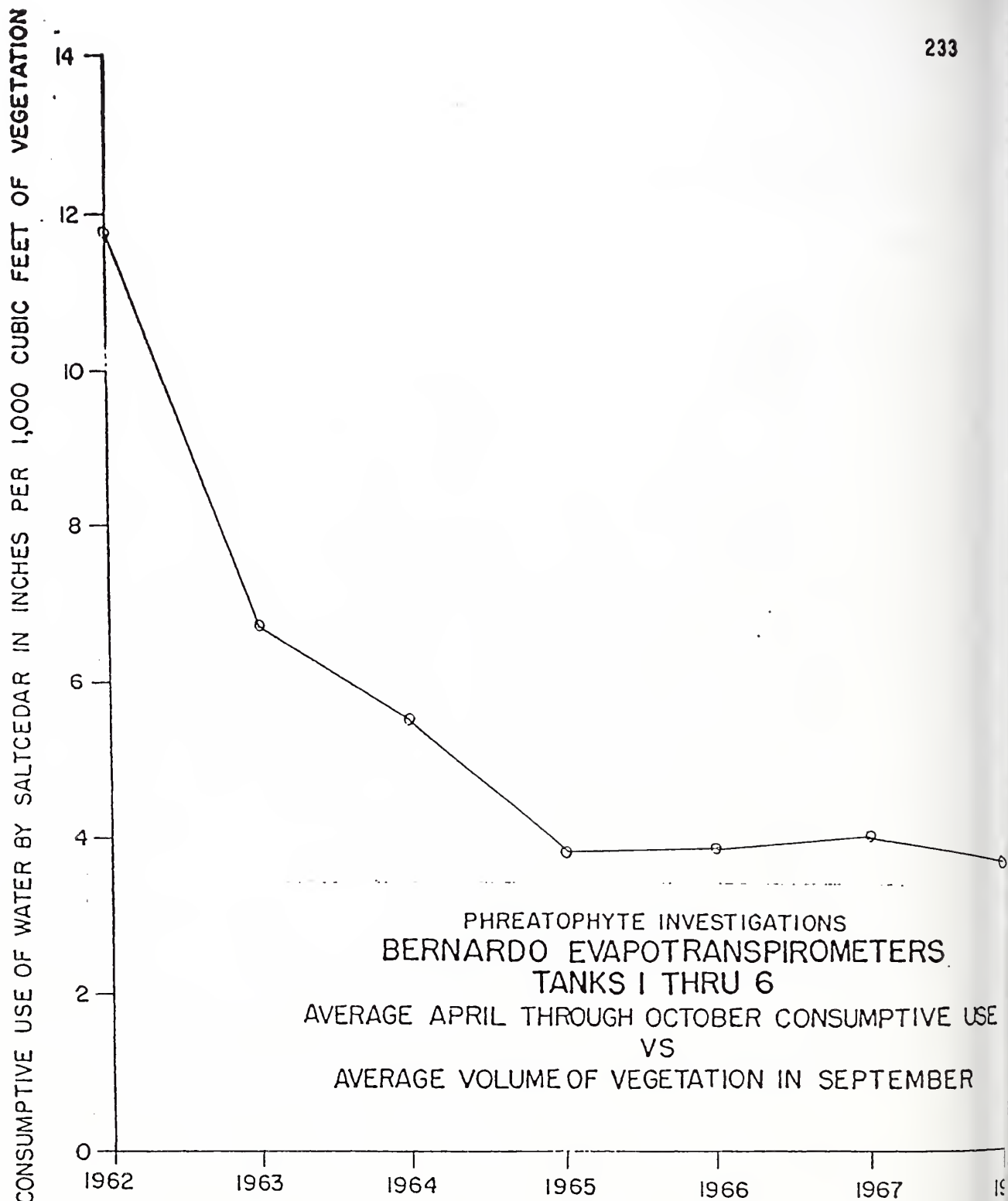


Fig. 22 Relationship between water use by saltcedar and age of plants in lysimeter tanks at Bernardo, NM, 1962-1968 (from Bur. Reclam. 1972).

3 ft water table is too shallow then the usual decrease of water usage with increasing depth would not hold true.

Bur. Reclam. (1972) concluded that the estimates of water use from tanks may be too high unless the progressive maturation (and decreasing water use) of the plants is considered (Fig. 22). Water use per unit volume of vegetation decreased by two-thirds during the first 3 years but remained nearly constant thereafter (Fig. 22). Water use was not necessarily dependent on depth to water table. The straight-line method of calculating water use at 100% volume-density also would cause overestimations because of variation in time required by stands to reach this density, and some never reach it.

Horton (1976 and in Brown 1989) speculated that the differing results at Bernardo might be caused by the higher elevation (4728 ft elevation) and cooler temperatures: perhaps saltcedar could extract water equally well throughout the summer from the deep depths at the cooler temperatures of Bernardo; whereas at the hotter Buckeye site, water movement from the deeper depths was reduced more than from the shallower depths. ---

In 1969, the experiments were changed at the Bernardo site to measure: 1) water use by Russian olive, 2) effect of salinity on water use, 3) effect of suddenly lowering the water table on water use by saltcedar, 4) water use by saltgrass, and 5) additional data on evaporation from bare soil. In early 1971, 16 additional small tanks (55-gal steel drums) were installed in cooperation with the Biology Department, New Mexico State University, to measure water use by saltgrass. The experimental layout and operation of the tanks from 1969 through 1973 was described by Bur. Reclam. (1973).

Water use by saltcedar declined by 15% when salinity was increased to 5000 ppm in Tanks 3 and 4 in 1969; use remained more or less constant for 4 years but declined slightly the fifth year, 1973. Water use during this

*Is this report on saltcedar only?*

period averaged 1.74 ft/yr at a 3 ft water table and was only 2.57 ft/yr at a 5 ft water table; this was consistent with the results of the previous experiment (see above) which indicated that a 3 ft water table is too shallow for optimal growth (Bur. Reclam. 1973). When the water table was lowered suddenly in Tank 6 from 5.65 to 9.0 ft by pumping, water use decreased by 46% the first year (from 3.37 to 1.82 ft) but returned to a 3.20 ft usage the next year. When the water table was lowered gradually by evapotranspiration from 3.0 to 9.0 ft, water usage decreased by 34% the first year (from 4.07 to 2.67 ft) and required 2 years to return to near previous levels.

The saltcedar in one tank burned in 1971 which caused a 34% reduction in water use (3.2 to 2.1 ft) that year but usage increased to near normal the following year.

Water use by saltgrass was measured in small tanks (55-gal drums) and 2 large tanks (1000 sq ft surface) from 1970 to 1973 (Bur. Reclam. 1973). In the 2 large tanks, saltgrass (Distichlis spicata) used an average 2.59 ft at a 1 ft water table and 1.58 ft (39% less) at a 2 ft water table (avg. of 3 yrs) in an average stand and density of plants. In the small tanks, it used an average (2-year) of 2.31 ft in open sun and 1.52 (34% less) under a 50% shade with a dense stand of plants; use at the 2.5 ft table was 18% less than at the 2 ft water table in open sun but there was no difference in the shade.

Evapotranspiration from bare ground in the 8 small barrel tanks (nos. 15, 16, 21, 22, 23, 24, 29, and 30) (2-year average) was 0.72 ft at a 2 ft water table and 0.94 ft at a 2.5 ft water table. Very little reduction occurred in the tanks with 50% shade (Bur. Reclam. 1973). In the 3 large (1000 ft<sup>2</sup>) tanks with bare soil, yearly evaporation (April through October) was as follows (Bur. Reclam. 1973, his Fig. 3):

<u>Water table (ft)</u>	<u>Tank-years (n)</u>	<u>Evaporation (ft/yr)</u>
0.5	2	1.85
1.0	5	1.71
2.0	4	1.45
3.0	6	0.85
5.0	4	0.26

#### D. Transpiration Wells

The concept of using diurnal fluctuations in the water table to estimate water use was first proposed by G. E. P. Smith of the University of Arizona in an unpublished paper in 1922 (Muckel 1966). By this method, shallow wells are sunk a few feet into the water table and instrumented to record changes in the water level. The method measures water usage in a small area in the field and can distinguish use by plant species if only one species grows within the area measured.

White (1932) used the method in the Escalante Valley of southwestern Utah to measure water usage by alfalfa and several native shrubs (no saltcedar was present). In general, the water table began declining between 9-11 a.m., reached its lowest point at 6-7 p.m., began rising at 7-9 p.m., and reached the daily high level at 7-9 a.m. During the growing season, daily withdrawal was more than nightly recovery and the level gradually declined. Wells in bare fields or during the dormant season did not show daily fluctuations. The daily fluctuation during August for willows was ca. 0.20 to 0.24 ft but for greasewood was only ca. 0.10 ft. White (1932) calculated water use by the equation:

$$Q = y (24r \pm S), \text{ where}$$

Q = groundwater withdrawn

y = specific yield of the soil (ratio)

r = hourly rate of rise in water (midnight to 4:00 a.m.)

S = net fall or rise of water in 24 hr.

UNITS?

Gatewood et al. (1950) also used data from 18 transpiration wells (8 in. diam.)--8 surrounded by saltcedar and others by baccharis, mesquite, and cottonwood to estimate total water usage on a 46-mile reach of the Gila River. In the saltcedar areas, depth to the water table varied from 3.8-5.3 ft for the shallowest well to 7.5-8.5 ft for the deepest well. They detected a regular diurnal fluctuation of ca. 0.1 ft; the level gradually fell each day as the plants used water faster than recovery at night. Surprisingly, they found that saltcedar continued transpiring a substantial amount throughout the night, so that daytime transpiration had to be multiplied by an average factor of 1.25 to obtain total daily transpiration; baccharis transpired very slightly at night and cottonwood not at all.

After adjusting for the coefficient of drainage of the soil, volume-density of the plants, and nighttime transpiration, they calculated that saltcedar used 72.4 inches, Baccharis 44.0 (61% as much as saltcedar), cottonwood 39.5 (55% as much as saltcedar), and mesquite 32.5 in. (45% as much as saltcedar) of water annually. The plants used water from April through October, with peak usage in June (94% was from May through September). The estimate from the wells was 6.4% below the average of all six methods used (Table 46) (Gatewood et al. 1950). The transpiration wells at Bernardo did not reliably estimate water use in the lysimeter tanks; sometimes they overestimated usage by twice or underestimated by one-half (Bur. Reclam. 1972).

Gary (1962) on the Salt River near Granite Reef Diversion Dam on the east side of Phoenix, AZ, observed characteristic diurnal fluctuations of ca. 0.2 ft in a saltcedar thicket with a water table at 0.5 to 2 ft. The decline began at 6-8 a.m. and the rise at 5-8 p.m. The fluctuation began in

early April and continued until late September. They concluded that a water table underneath transpiring vegetation has an irregular, undulating surface.

Theis (1951) had proposed that wells could be used to measure the normal water table level; then the phreatophytes could be removed and the change in the water table measured; and, finally, water could be pumped from the wells and the amount removed to return the water table to its original level would equal the amount previously used by the phreatophytes.

Gary and Campbell (1965) tested Theis' proposal by clearing the plants from a 25-ft diam. area around the observation well caused a ca. 1-1/2 ft rise in the water table but additional later clearings to 35 and 61 ft diam. did not cause an additional rise. In an enlarged study, 39 wells were dug in a 1/28 acre area surrounding a central well with a water-table recorder. Attempts to simulate transpiration by pumping from these wells was not successful. Pumping out 2.4 ft of water from the well lowered the water table 3-1/4 ft away by only 0.55 ft and at 6.2 ft away by only 0.037 ft. They found considerable variation between nearby wells, indicating that data from only one well at a site would be unreliable (Gary and Campbell 1965).

Theoretically, the method is usable wherever phreatophytes produce measurable diurnal fluctuations in the water table. However, these fluctuations are difficult to measure when plants use small amounts of water or when the water-bearing soil layers are loose (Gatewood et al. 1950). They concluded that errors in estimating the coefficient of drainage would cause major errors and that transpiration at night, extrapolation of results, and overlooking small quantities in base data could cause medium errors. Horton and Campbell (1974) suggested that wells should be used only to monitor changes in water table levels and to evaluate clearing projects; they doubted that wells could accurately measure water losses.

Transpiration wells have been used to obtain part of the data needed in other types of measurements. Gatewood et al. (1950) had available 1,426 observation wells near Safford to measure water usage by the "inflow-outflow," "chloride-increase," "seepage-run," and "slope-seepage" methods. In the Gila River Phreatophyte Project during the 1960's, 116 recording wells were used to obtain part of the data needed for the total "inflow-outflow" equation (Culler 1965; Culler et al. 1970, 1982).

Bureau of Reclamation (1972) concluded that the transpiration well method was not reliable. However, Bowie and Kam (1968) used transpiration wells successfully to measure changes in water usage before and after clearing phreatophytes at Cottonwood Wash, Mojave Co, AZ. Also, Trombel (1977) concluded that the method gave plausible values for water usage by mesquite at Walnut Gulch Experimental Watershed in southeastern Arizona when compared with other methods. Johns (1990) concluded that the method is acceptable but problems may occur with the accuracy of the measurements.

#### E. Inflow-Outflow Method

The "inflow-outflow" method (another type of "water-budget" or "water-inventory" method) measures all the water that enters, all that leaves, and the increase or decrease in water stored in an area:  $\text{inflow} - \text{outflow} - \text{storage} = 0$ . Measurements are needed of inflow and outflow of the river surface; river underflow; surface flow, spills and field waste from canals; inflow of washes; precipitation on and evaporation from river surface and wet sand bars; net underground inflow; and changes in storage in the river, channels and washes, in the ground-water reservoir, and in soil moisture (Gatewood et al. 1950). Water used by phreatophytes is calculated as the residual. The method has the potential to measure actual usage under field conditions. However, very exacting measurements of the various

parameters are required. The amount used by phreatophytes is small in comparison with total river inflow-outflow and this small amount is often masked by measurement error. Gatewood et al. (1950) noted that the accuracy of this method is reduced when the quantities of water measured greatly exceed use by phreatophytes; it is not applicable where the surface stream is excessively complicated by diversions and surface inflows. They concluded that measurements for only short periods could cause large errors and that inconstant underground flow could cause medium errors. Johns (1990) concluded that the inflow-outflow method is an acceptable technique but the quality of the data must be insured. He cited several excellent examples of water-budget techniques, including those of Bowie and Kam (1968) and Culler et al. (1982).

By this method, large-scale experiments have been conducted to measure water use by phreatophytes on the Gila River near Safford (Gatewood et al. 1950), on the Pecos River near Carlsbad (Robbins 1953), and on the Gila River near San Carlos (Culler et al. 1982). This latter was aimed at measuring the difference in water usage before and after clearing phreatophyte vegetation and is reported in the Sect. VIII,K, "Water usage before and after clearing" of this report.

On the Gila River near Safford, AZ, Gatewood et al. (1950) estimated water usage on 3 subreaches along the 46-mile reach of floodplain at 4290, 5180 and 5880 acre-feet per year or 6.82 ft. This was only 5.2% above the common mean of all 6 methods compared (Table 46).

On the Pecos River, NM, Robbins (1953) reported an attempt to measure water loss from the Artesia bridge to the head of McMillan Reservoir, 14 miles to the south. The floodplain here averaged ca. 1 mile wide for the northern two-thirds of the area and ca. 2 miles wide for the southern

one-third; it encompassed 13,534 acres of water-consuming areas, 10,159 of this in saltcedar. Blaney et al. (1942b, their Table 39) had estimated water losses from saltcedar at 54,257 A ft per year (4.5 ft/yr) from 1934-1940. This study could not measure losses by saltcedar because inflow from the west was indeterminate and because ca. one-fourth of the saltcedar was sprayed with herbicides during the study period (Robbins 1953).

The most extensive study involving saltcedar was the Gila River Phreatophyte Project (Culler et al. 1982 and other papers). Horton and Campbell (1974) reviewed four other studies of other vegetation types. These are discussed below in the section "Water usage before and after clearing phreatophytes."

#### F. Other Methods of Measurement

Gatewood et al. (1950) used three additional methods, in addition to the lysimeter tanks, inflow-outflow, and transpiration well methods described above, to measure water usage on the 46-mile study reach of the Gila River near Safford, AZ. None of the methods could distinguish usage by different plant species and several of the factors needed for the calculations were obtained by indirect measurements.

1. Seepage-run. In this method, the amount of water leaving a reach of a river, plus that evaporating from the soil surface, is subtracted from the amount of water entering the reach, plus seepage entering from the sides and rainfall; the remainder is the amount used by the plants. Gatewood et al. (1950) noted that, theoretically, this method is usable where a surface stream gains water from the ground-water reservoir. Practically, it cannot be used when the surface stream flow is highly complicated by sporadic diversions and inflows or where groundwater inflow is not reasonable constant. They concluded that interpolation of data between runs

and false assumptions that underground flow is constant would cause medium errors.

Gatewood et al. (1950) used 1426 observations wells (1-1/2 in. diam.) to measure water levels. They calculated that the phreatophytes used 6.66 ft/yr, or 31,440 A ft when extrapolated to the entire 46-mile study reach; this was the closest to the measurements in lysimeter tanks but was 18.6% above the common mean of all methods used (Table 46).

2. Slope-seepage. This method measures the slope of the water table from the outer edges of the flood plain to the river edge. The rate of movement of water depends on the slope and the transmissibility of the soil. The difference in flow between the outer edge and the river edge, adjusted for storage, is the amount lost by transpiration and evaporation. Gatewood et al. (1950) noted that this method is usable where a surface stream is in contact with the ground-water reservoir and where phreatophyte usage causes a measurable change in slope of the water table. They concluded that determining the mean slope would be the only likely source of major error in their tests.

At Safford, measurements were made along 15 seepage runs across the floodplain. The slope was 8.4 to 11.6 ft/mile on the north side of the river and 2.9 to 5.2 ft/mile on the south side. Great differences in flow were noted between summer measurements where plants were using water and winter measurements when they were dormant (Gatewood et al. 1950).

By this method, Gatewood et al. (1950) calculated that phreatophytes along 3 of the 4 reaches used 5.44 ft/yr, or 18,270 A ft when extrapolated to the 4720 acres of vegetation at 100% volume-density; this was 19.9% below the common mean of all methods (Table 46).

3. Chloride-increase. This method measures the increase in salt concentration in groundwater as it moves across the floodplain to the river. During this movement, part of the water is either taken up by plants or evaporates; however, evapotranspiration does not remove salts in the water and salt concentration increases from the edge to the river; the amount of water lost is calculated from the increase in salt concentration. Gatewood et al. (1950) noted that this method is usable where ground-water inflow is constant in amount and direction and where sufficient ground water is discharged to prevent the accumulation of dissolved minerals. Application is limited where little or no surface water percolates to the water table. They concluded that the assumption that minerals did not accumulate in bottomland could cause major errors and that extrapolation of results, the constancy of underground flow, inflow of minerals from fill beneath the bottomland, and recharge from the river could cause medium errors.

At Safford, Gatewood et al. (1950) used 480 of the 1426 observations wells (they ignored the amount of salt taken up by saltcedar and excreted by the leaves). The vegetation used ca. 5.36 ft/yr along 3 of the 4 reaches, or 18,000 A ft when extrapolated to the entire area; this was 16.2% below the common mean of all methods (Table 46).

#### G. Evapotranspiration Tent Method

The evapotranspiration tent method is intermediate, between laboratory measurements and micrometeorological field measurements. Plants growing in the field are covered with a clear, air-tight plastic cover equipped with a fan that circulates the air through an entry and exit opening. Sensors measure the <sup>flow rate and for</sup> difference in moisture content of the incoming and outgoing air, from which evapotranspiration is calculated. It can measure actual usage of the plants growing in natural conditions but has been criticized mostly

because of possible effects of the cage itself in altering natural transpiration.

Decker and Wetzel (1957) developed an infrared gas analyzer that acted as a fast-acting hygrometer to measure transpiration by vapor production of saltcedar enclosed in a chamber. In their tests in the laboratory, transpiration of 20-40 cm tall seedlings increased linearly from 0.26 mg/sec/shoot at zero light to 0.79 at 600-ft candles; light saturation began between 600 and 3000 ft candles and transpiration was 1.21 mg/sec/shoot at 3000 ft candles. Transpiration decreased by 14% as humidity in the chamber increased from 5.4 to 13.0 mg/l absolute humidity; transpiration increased by 18% as temperatures in the chamber increased from 30° to 40°C.

Decker and Wien (1960) showed that transpiration by Tamarix twigs enclosed in the chamber increased briefly when the stems were cut, then decreased by ca. 80% within 15 min. Also, with uncut stems, transpiration increased rapidly from 2 to 9 mg/min within 5 min after a 3000 ft-candle light was turned on and decreased to the original level within 5 min. after the light was turned off.

Decker et al. (1962) enclosed a 10-ft diam. plot of bermudagrass and saltcedar in a clear plastic inflated tent and measured evapotranspiration with their infrared gas analyzer as the difference between inflow and outflow from the tent. The average of five 24-hr measurements during June and July was 16.3 kg/d<sup>7</sup> water evaporated in the cage (= 16.3 mm/d<sup>d</sup> ~~ground surface area~~). The diurnal pattern of evapotranspiration followed the pattern of light intensity and humidity deficit, but continued at a low rate throughout the night. Measurements made over bermudagrass plots with increasing densities of saltcedar showed increasing evapotranspiration; they calculated that evapotranspiration could be reduced by 50% by substituting bermudagrass for

saltcedar. They estimated that the effect of the plastic tent reduced evapotranspiration from the saltcedar plot by 22 percent.

Lee (1966) severely criticized the tent because of the enclosure effect; he found that transpiration increased by 2-70% inside the tent and found a strong stratification effect inside. Shachori et al. (1962) in Israel found only a 1.0-1.5°C temperature increase inside and only a 2.5% increase in evapotranspiration inside the tent. Sebenik (1967) found differences of 5.5°F in air temperature and 3.8° in leaf temperature. Mace and Thompson (1969) also found large differences in air temperature inside the Decker-type tent. However, they designed a tent with increased, and more uniform, wind movement that produced no significant increase in temperature. They suggested that this modified tent would give reliable measurement of evapotranspiration of plants growing in natural conditions.

Sebenik and Thames (1967) used Mace's modified tent to measure evapotranspiration by saltcedar on the San Pedro River, AZ. However, their water-loss figures are among the largest published, probably due in part to the enclosure effect. Until it is evaluated more critically, Horton and Campbell (1974) concluded that the tent should not be used to estimate water usage by phreatophytes. Johns (1990) recommended that research results based on the method be questioned and verified before being used, although many of the problems <sup>(e.g. . . . .)</sup> may now have been solved.

#### H. Empirical Equations

A very large amount of research has been done since the 1700's to understand evaporation and transpiration. A bibliography of the more recent work, especially as relating to North American phreatophytes, was published by Horton (1973). Data from lysimeter tanks were often used to estimate water losses from phreatophytes on flood plains (Blaney 1933; Blaney et al. 1938;

move to p 249 not an empirical method! 246  
Blaney et al. 1942a; Gatewood et al. 1950). Because these data applied only to one set of conditions, and because collecting the data was time consuming and expensive, workers attempted to develop equations that would predict water use based on readily available climatic variables.

The Bowen Ratio (Bowen 1926) has been widely used to describe essential aspects of transpiration. A description of and discussion of the use of the Bowen Ratio was recently given by Weeks et al. (1987). More than 20 empirical methods of estimating evapotranspiration have been proposed, the more important of which (as listed by van Hylckama 1980a) are those of Blaney and Morin (1942) and Blaney and Criddle (1962); of Thornthwaite (1948) and of Jensen and Haise (1963). Detailed descriptions of the methods used in various models are given by Cruff and Thompson (1967) and Jensen (1973).

Using these methods, Blaney (1957, 1961) estimated water use by saltcedar at 7 locations along the Pecos River in New Mexico and Texas at from 51.6 to 72.0 in/year.

Blaney and Criddle (1962) developed an equation that differentiates between vegetation species and predicts evapotranspiration based only on easily obtainable mean monthly temperatures.

Rantz (1968) developed values for the all-important coefficient, K, the empirical consumptive use coefficient that describes vegetal species, density of growth, and depth to the water table. He presented graphs of K values for saltgrass, mesquite, sacaton, baccharis, cottonwood and willow, and saltcedar at water table depths from 1 to 8 feet. The saltcedar curve (based on data from Gatewood et al. 1950) had the largest K value, from ca. 1.1 at 8 ft to 1.8 at 2 ft.

Culler et al. (1976) further refined the Blaney-Criddle equation by including factors estimating canopy cover at 5 different densities,

evaporation from bare ground, and nonlinearity of  $K$ . They also made a preliminary attempt to develop a method to include estimates of canopy cover obtained by infrared aerial photography into the equation.

Van Hylckama (1980a) compared 15 models previously developed by other workers with water usage from two lysimeter tanks (Nos. 3 and 5) at Buckeye from 1961-65 at a 1.5 m water table. The models (using data from the lysimeter site) predicted long-term water use to within 48% to 128% of the lysimeter tank measurement but none could predict short-term usage (hours, or even minutes) as can the micrometeorological equations discussed in the next section. Three of the models were quite close (94%, 98% and 104%) to the tank measurement; two of these were based on pan evaporation.

Culler et al. (1982) found that of 4 models tested, the Blaney-Criddle model and the solar radiation model of Jensen and Haise gave the best approximation of water usage on a 15-mile reach of the Gila River near San Carlos, AZ (discussed in more detail below in the section "Water use before and after clearing phreatophytes."

### I. Micrometeorological Methods

Two researchers stand out as leaders in developing micrometeorological methods of measuring transpiration from the leaf surface of saltcedar and in developing equations that predict transpiration based on easily measurable climatic variables. T. E. A. van Hylckama of the U.S. Geological Survey conducted research at the Buckeye site on the Gila River, presented in a series of papers from 1960 to 1980. Lloyd W. Gay and his coworkers of the School of Renewable Natural Resources, University of Arizona, Tucson, worked at the Bernardo, NM, site on the Rio Grande and also near Blythe, CA, and Ehrenberg, AZ, on the Lower Colorado River. The research was presented in a series of papers from 1976 to 1985. The different methods and approaches

have been thoroughly discussed in Conference Proceedings of the American Society of Agricultural Engineers (Jensen 1966).

# 1. Vapor-flow Methods.

a. Atmospheric-water-balance method.--This method considers the quantities of moisture entering and leaving a column of air, with the soil surface as the lower boundary. The method requires a large area and a tall column of air for accurate measurements. At Buckeye, the distance between instruments and the height of the column that could be measured were far too small to integrate windspeed, temperature and vapor-pressure data to successfully measure transpiration by saltcedar (van Hylckama 1980a).

b. Eddy-correlation method.--The "eddy-correlation" or "eddy-transfer" method was suggested by van Hylckama (1980a) as possibly the most promising method of all. It can be considered the most fundamental approach to the measurement of evapotranspiration because the turbulent air movements that give rise to eddy diffusion are measured together with fluctuations in humidity. The method assumes that a moving parcel (or glob) of air carries with it the heat, water vapor and momentum it contained from the start as it moves through and out of the vegetation. Measurements are made of the ~~density~~ <sup>vertical wind speed</sup> ~~ity, velocity~~ and humidity of the air as close to the surface of the plant as possible, measured once per second or more often, <sup>(usually ca. 10 Hz)</sup> requiring computerized data handling. The instrumentation is very complex but is easily portable. Weeks et al. (1987) described this method and compared it with the energy budget method to measure water usage by saltcedar on the Pecos River.

The mean upward flux of humidity per unit mass is expressed in equation (3) of van Hylckama (1980a) as:

$$F = P_a w q$$

(units?)  
 where  $\bar{P}_a$  is density of the air ( $\text{g/cm}^3$ ),  $w$  is vertical velocity, and  $q$  is humidity and the bar indicates average condition during a selected period.

~~The Buckeye Station was not equipped for this model (van Hylckama 1980a).~~

c. Bulk aerodynamic (or mass-transfer) method.--This method was described but was not used by van Hylckama (1980a), but it was an integral part of the combination approach that he developed. Two approaches have been developed. The Dalton approach measures vapor transfer along a gradient of moisture which depends on turbulence (wind speed) above a surface. The aerodynamic or profile approach considers temperature, humidity and wind speeds at two or more levels above a surface.

2. Energy-budget (or Energy-balance) Method. This method compares all incoming with all outgoing radiation, plus what is stored in the soil, air and vegetation (van Hylckama 1980a). The difference is that part of the radiation used to evaporate water from moisture on and in the soil and on and in the plants. Parameters which must be measured are radiation received at the surface, <sup>( $R_n$ )</sup> heat flux into and out of the ground, <sup>( $G$ )</sup> sensible and latent <sup>( $H$ )</sup> heat fluxes into the air, ~~and latent heat of evaporation~~. The equation can be written:

$$R_n = LE + A + G \quad (\text{Equation 17, van Hylckama 1980a})$$

where  $R_n$  is net radiative flux received at the surface,  $G$  is heat flux into and out of the ground,  $A$  and  $LE$  are sensible heat flux and latent heat flux into the air, and  $L$  is latent heat of evaporation. The ratio  $A/LE$  is known as the Bowen ratio. The Buckeye site did not have proper instrumentation for this model, measurements using the Bowen ratio were erratic, and the method could not be used (van Hylckama 1980a).

Van Hylckama (1968a) also found that the "oasis effect" influenced water usage (as had Blaney (1933) with different species). Tanks 7 and 8 that were

→ Relevant to E Bal Method - in this area of place 7

surrounded by bare solid used 90 cm (3 ft) more water per year than tanks surrounded by dense saltcedar thickets. In a preliminary study to measure evapotranspiration by the energy-budget or mass-transfer methods, van Hylckama (1970b) measured patterns of air movement above and within a saltcedar thicket at the Buckeye station. In 90% of the cases, wind profiles above the stand could be represented by the simple logarithmic equation:

$$u_z = (U_0/k) \ln (z/z_0)$$

where  $u_z$  is velocity at height  $z$ . The roughness length ( $z_0$ ) varies with a stability ratio similar to Richardson's number. The friction velocity,  $U_0$ , depends on wind speeds above the vegetation and von Karman's constant,  $k$ , is 0.41. Within thickets, he found considerable turbulence, irregular wind inversions and tunneling during daylight hours.

a. Studies by van Hylckama.--Van Hylckama (1980a) concluded that one must combine the principles of energy budget and a mass-transfer term to obtain reliable estimates of water use. He developed his equation 26:

$$E_0 = 1/L \cdot \frac{(\Delta/\gamma) H + [(pe)/p] (d_a/r_a)}{\Delta/\gamma + 1 + r_s/r_a} \quad \text{check this!}$$

where  $E_0$  is potential evaporation,  $H$  is sum of ~~energy inputs at the surface~~ <sup>( $R_n - G$ )</sup> ~~(except A and LE)~~,  $e$  is the ratio of molecular weight of air and water (0.622),  $d_a$  is the vapor pressure deficit,  $r_a$  is external resistance,  $r_s$  is stomatal resistance,  $\Delta$  is the slope of the curve when saturation vapor pressure is plotted against temperature,  $\gamma$  is the psychrometric constant (ca.  $0.65^\circ\text{C}^{-1}$ ), and  $p$  is density of the air ( $\text{g}/\text{cm}^3$ ). Units!

Instrumentation at the Buckeye site measured wind velocity, air temperature, rainfall, water vapor, solar radiation, soil temperature and heat flow, and soil moisture. Van Hylckama (1980a) presented graphs of all these parameters in saltcedar thickets for various periods of time.

Water usage in two of the large lysimeter tanks during 5 budget periods of 72 hr each taken throughout the growing season at Buckeye averaged 16.8 mm per day in May, 19.3 mm in June, 21.0 mm in July, 12.2 mm in August, and 11.9 mm in September (van Hylckama 1980a). This gave a total for the year of 2280 mm. Predictions of potential evapotranspiration using the above equation agreed quite acceptably (within +10.6 to -6.7%) with actual measurements in the lysimeter tank at Buckeye during the same dates (Fig. 23). This was the only model tested by van Hylckama (1980a) that gave reasonably accurate short-term predictions on an hourly- or shorter-term basis. Very good long-term values can be obtained by adding the hourly values.

For long-term prediction, van Hylckama (1980a) compared 15 models developed by other workers that used means of monthly values (these models cannot predict short-term water usage). The 15 models tested estimated water usage at from -48% to +128% of the lysimeter values for saltcedar. He concluded that for a rough estimate of water use, three models were acceptably close and used easily obtainable data; these were the Weather Bureau pan evaporation method which estimated 104% of the lysimeter value, the model of Eagleman (1967) which estimated 98% of the lysimeter value, and the model of Morton (1975) which estimated 94% of the lysimeter value. Of course, the lysimeters may not estimate the "true" water use by saltcedar in nature because of various problems with the lysimeters themselves or with the surrounding habitat (van Hylckama 1974, Gatewood et al. 1950).

Much evidence gathered by van Hylckama (1980a) indicates that saltcedar often does not transpire at its potential rate. High salinity of available groundwater and greater depths to the water table greatly reduce the transpiration rate below the potential and ~~heat-induced stomatal closure in early summer afternoons also reduces transpiration.~~

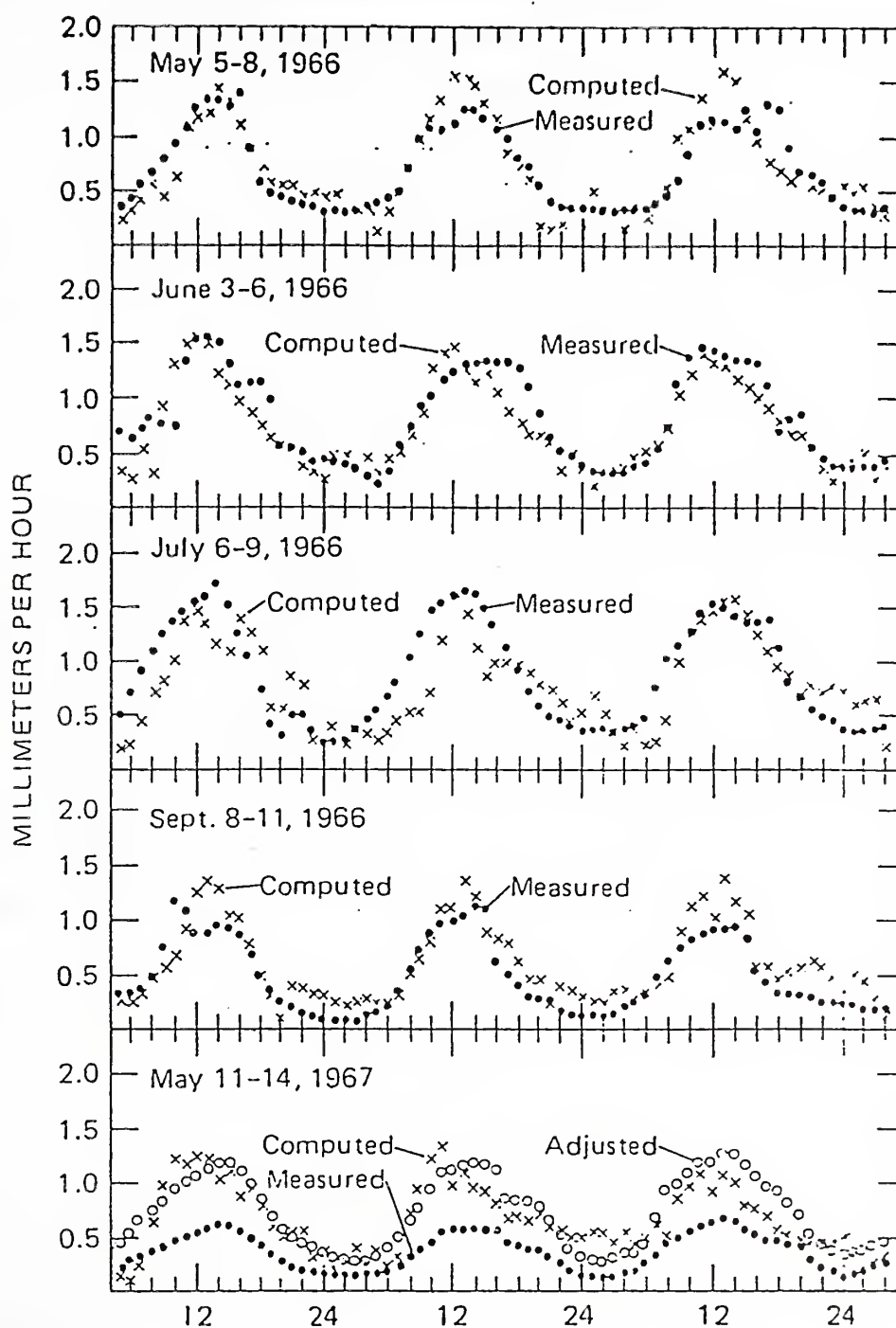


Fig. 23 Computed evapotranspiration, using equation 26, versus that measured in Tank 2 at the Buckeye project in millimeters per hour for 5 periods of 3 days each. The oooo (adjusted) line on the bottom graph compensates for salinity buildup (from van Hylckama 1980a, his Fig. 45).

b. Studies by Gay and coworkers.--Lloyd W. Gay and his coworkers developed diffusion resistance and energy budget methods for estimating water use by saltcedar. The experiments were conducted on the Rio Grande at the Bernardo, NM, site (where comparisons could be made with the large (1000 sq ft area) lysimeter tanks) and in the floodplain of the Lower Colorado River, 50 km south of Blythe, CA, and Ehrenberg, AZ. This latter site is one of hottest and driest regions in the United States. The average annual rainfall is 78.7 mm (3.1 in.) and temperature frequently exceeds 46°C (115°F) in midsummer; the elevation <sup>is</sup> ~~was~~ 90 m above sealevel. The study area on the Lower Colorado was a dense thicket of saltcedar of 10 km<sup>2</sup>, with a fetch of 1 km to the west and 2-3 km in the other directions; <sup>depth to the water table</sup> ~~depth to the water table~~ was ca. 3.3 m and the saltcedar was ca. 7 m high. The growing season was arbitrarily set at 233 days (March 23–November 11).

Gay et al. (1976) <sup>at Bernardo</sup> tested a diffusion resistance model during one day, June 14, 1975. Measurements were required of net radiation above the canopy, soil heat flux, dry- and wet-bulb temperatures at two levels above the canopy, and wind velocity at three levels above the canopy. The components of the energy budget equation were calculated for each half-hour. The equations did not contain any stomatal or other plant parameters. The calculated energy-budget showed energy gains from net radiation totaled 432 cal/cm<sup>2</sup>, while energy losses (cal/cm<sup>2</sup>) were 14 to stored energy, 31 to convection, and 387 to <sup>latent heat flux</sup> ~~evapotranspiration~~. This energy loss to evapotranspiration was equivalent to <sup>an evaporation of</sup> ~~the latent energy in~~ 6.5 mm <sup>of</sup> ~~water~~. This compared favorably with the 6.7 mm measured amount used in the same day in the nearby lysimeter tanks, although the amount used at different times of the day was different.

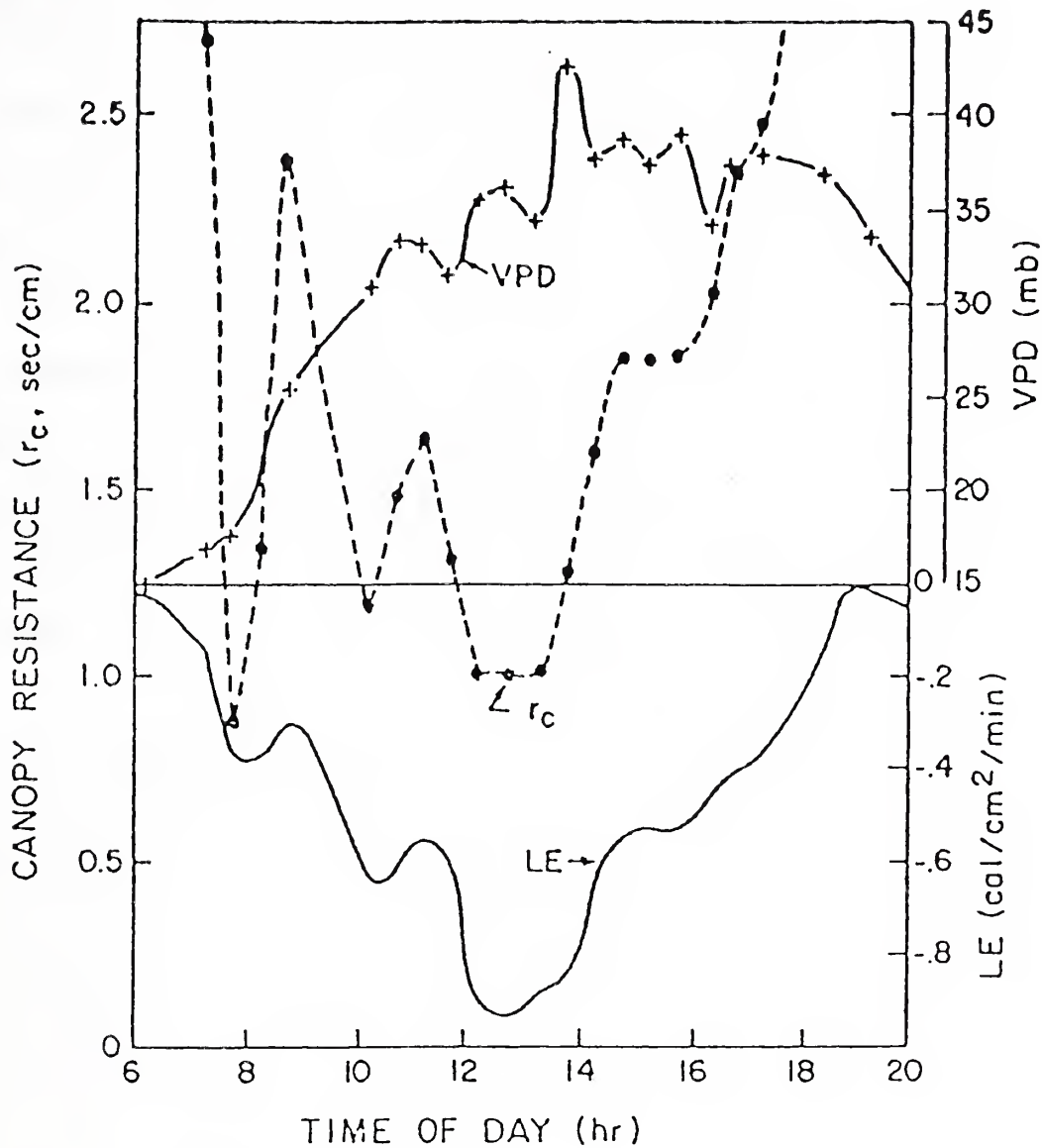


Fig. 24 The trend of canopy diffusion/resistance,  $r_c$ , with respect to vapor pressure, VPD, and latent energy, LE (from Gay et al. 1976, their Fig. 2).

deficit

hot day

location?  
date?

Gay et al. (1976) also computed canopy diffusion resistance and transpiration from the canopy. Canopy resistance interacted with vapor pressure to control water losses. Instead of water loss increasing directly with increasing vapor pressure deficit as predicted by the equations, canopy resistance increased in the afternoon and limited water losses (Fig. 24). These equations predicted water losses in the lysimeters by  $\pm 12$  percent.

Gay and Sammis (1977) on the Lower Colorado River, estimated transpiration from a simple diffusion resistance model using the easily obtainable air temperature and RH, solar radiation, leaf diffusion resistance measured with a porometer, and plant water potential measured with a pressure bomb. Surface area was measured with a densitomer from dried leaves from which they calculated  $200 \text{ cm}^2/\text{g}$  for saltcedar leaves and  $150 \text{ cm}^2/\text{g}$  for mesquite leaves. This model can be applied to plant communities of irregular dimensions, or clumps, while the Bowen ratio or energy budget methods require large, uniform stands.

Leaf resistance measurements indicated that the stomata were open soon after sunrise. Resistance (stomatal closure) increased to a plateau from midday until sunset, then increased sharply after dark (stomata closed). Solar radiation and leaf resistance were not closely correlated (Fig. 25). However, curves of leaf resistance and vapor pressure deficit were quite similar until dusk, after which resistance rose sharply while VPD decreased (Fig. 26).

Transpiration rate reached a maximum during late morning, then decreased in the hot afternoon. This suggests that increasing leaf resistance (stomatal closure) operated to counteract the evaporative demand on hot afternoons. Transpiration loss from saltcedar varied from  $0.27 \mu/\text{cm}^2\text{-s}$  at 11:00 p.m. to 2.78 at 10:30 a.m.; maximum for mesquite was 11.24 at 9:35 a.m. This

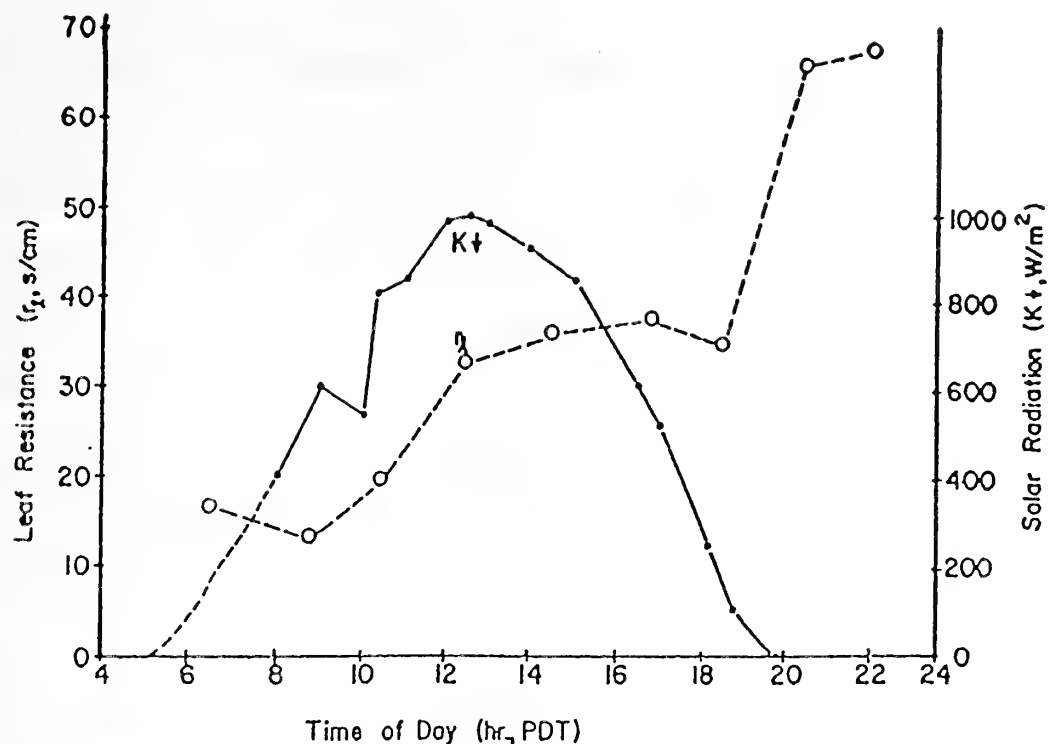


Fig. 25 Solar radiation ( $K\downarrow$ ) and leaf resistance ( $r_e$ ) of saltcedar, Ehrenburg, AZ, June 17, 1976 (from Gay and Sammis 1977, their Fig. 1).

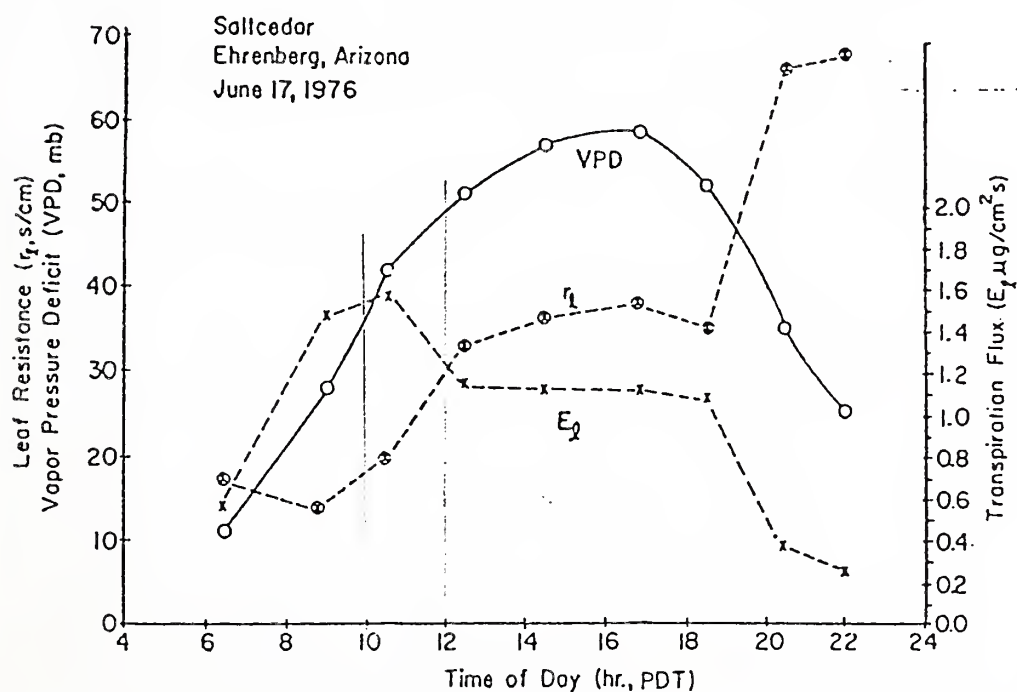


Fig. 26 Vapor pressure deficit (VPD), leaf resistance ( $r_e$ ) and transpiration rate ( $E_e$ ). Saltcedar, Ehrenburg, AZ, June 17, 1976 (from Gay and Sammis 1977, their Fig. 2).

translates to a maximum of 0.1 mm/hr for saltcedar, or in a dense stand with a leaf area index (LAI) of 8, to 0.8 mm/hr, or 8 to 10 mm per day in clear summer weather (Gay and Sammis 1977). They state that these estimates can be extrapolated to stands in the field by multiplying by leaf area in the field. Although mesquite had a higher rate of transpiration, it had a lower LAI of ca. 3, which would give a transpiration rate of ca. 1 mm/hour in a stand in the field. This contradicts the finding of Gatewood et al. (1950) that mesquite uses only half as much water as saltcedar. However, van Hylckama (1970a, 1974) found that water usage does not increase linearly as plant density increases.

Gay and Fritschen (1979) conducted an energy budget analysis of water use by saltcedar at the Bernardo station. They used the Bowen ratio, which required the same inputs of data as in the 1975 study (Gay et al. 1976). The field measurements were made continuously for a 5-day period in June 1977 and the data totaled for each half-hour period. The data for one day are shown in Fig. 27; data for the other 4 days were very similar.

Latent energy for Site 2 ( $LE_2$ ) was ca. 15% less than for Site 1 ( $LE_1$ ), a difference which was significant ( $P=0.05$ ). The 5-day means were:  $LE_1 = 513 \pm 31 \text{ cal/cm}^2$  and  $LE_2 = 433 \pm 12 \text{ cal/cm}^2$  which translates to a mean daily evaporation of 9.0 and 7.4 mm, respectively. The saltcedar at Site 2 was sparser and of lower vigor than at Site 1. This was very close to the evapotranspiration measured in 4 large, nearby lysimeter tanks planted to saltcedar (Table 51). The vegetation in Tanks 5 and 6 was taller and even more vigorous than in energy budget Site 1, while that in Tanks 3 and 4 was similar to that in energy budget Site 2. Allowing for these differences in vegetation, Gay and Fritschen (1979) considered that the measurements by the energy budget and with the lysimeter tank were in

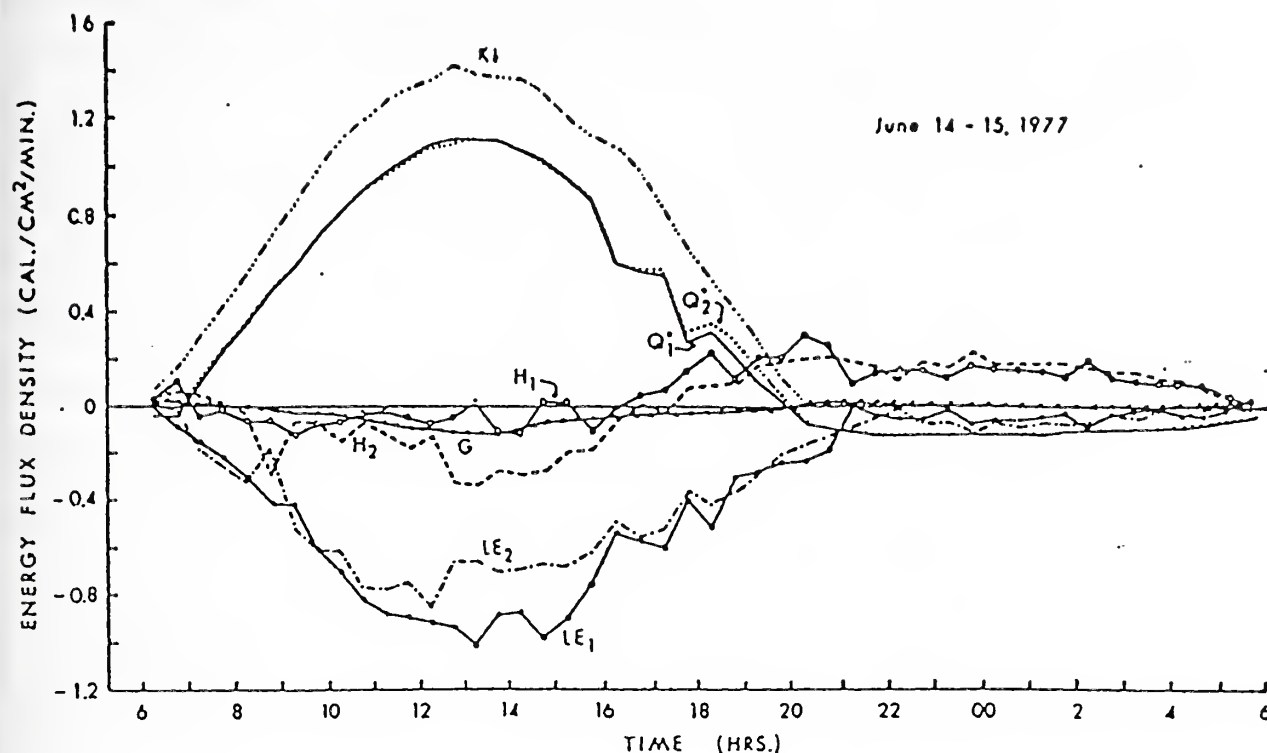


Fig. 27 Energy transfer over saltcedar at two sites near Bernardo, NM, June 14-15, 1977. The time axis is Mountain Daylight Time (MDT). Symbols are  $K\downarrow$ , solar radiation;  $Q^*$ , net radiation;  $G$ , soil heat flux;  $H$ , convection; and  $LE$ , latent energy. Subscript 1 is the site with the taller, more vigorous vegetation (from Gay and Fritschen 1979, their Fig. 1).

Table 51. Evapotranspiration of saltcedar at Bernardo, NM, in 1977 (from Gay and Fritschen 1979).

	Evapotranspiration (mm/24 hr) <sup>a/</sup>					
	$LE_1$	$LE_2$	$lys_3$	$lys_4$	$lys_5$	$lys_6$
June 14	8.8	7.7	6.4	6.5	8.8	9.0
June 15	9.5	7.4	6.5	6.9	9.3	9.1
June 16	9.5	7.4	6.2	6.5	9.0	9.0
June 17	8.4	7.3	6.6	6.8	9.2	9.3
June 18	<u>8.6</u>	<u>7.2</u>	<u>6.2</u>	<u>6.8</u>	<u>9.4</u>	<u>9.4</u>
Mean	9.0	7.4	6.4	6.7	9.2	9.2
Means	8.2		7.9			

<sup>a/</sup>  $LE_1$  and  $LE_2$  = Latent energy sites 1 and 2;  $lys_3$  through  $lys_6$  = lysimeter tanks 3-6.

excellent agreement. The experiments also pointed out the importance of taking replicated samples to allow for differences in vigor and density of the stand of plants measured.

Gay and Hartman (1982) (also reported by Gay 1985) measured evapotranspiration of saltcedar on the Lower Colorado River. The data were averaged for each 12-min period (40 measurements). Data were collected on 8 occasions throughout the growing season, 2 to 4 days on each occasion, during a total of 21 days and 11 nights during 1981. Daily water consumption during daylight hours ranged from ca. 2 mm in spring and fall up to 12 mm in midsummer. Nighttime use was from 0.08 mm in spring and fall to 0.6 mm in midsummer. Totals for the year were calculated at 1548 mm during the day and 89 mm at night, for a total of 1637 mm. This should be increased by 90 mm for rain-fall, giving a total evapotranspiration of 1727 (5.67 ft) over the year. This agreed closely with the estimate of 1359 mm (excluding precipitation) made in the same area (Bur. Reclam. 1964) but in a less vigorous stand of saltcedar. An estimate of 1700 to 1750 mm (5.58 to 5.74 ft) yearly evapotranspiration is reasonable for dense saltcedar along the lower Colorado River (Gay 1985). Considering the extreme climate of the area, this is probably the maximum water usage by natural stands of saltcedar anywhere in the U.S.

Johns (1990) believed that these studies of Gay were well conducted and that the value of 5.7 ft water usage on the Lower Colorado could be used directly in the vegetation management studies of that area. Weeks et al. (1987) reviewed the work of Gay and his co-workers and of van Hylckama; he compared the energy budget method with the eddy <sup>correlation</sup> transfer method and used both to measure evapotranspiration before and after clearing saltcedar along the Pecos River. *Results dismissed later.*

## J. Water Stress - Diurnal Pattern of Usage

Mace (1971) measured transpiration of saltcedar in the laboratory at vapor pressure deficits (VPD) of 24, 37, 87, and 112 mm Hg, ~~growing at each VPD in solutions producing 0.3 (351 ppm NaCl), 4.0 (5612 ppm), 8.0 (11,224 ppm), and 12 (16,836 ppm) atmospheres osmotic pressure.~~ <sup>STB</sup> Transpiration increased linearly as VPD increased at osmotic pressures of 0.3 and 4.0. However, at osmotic pressures of 8.0 and 12.0, transpiration increased curvilinearly, reaching an asymptote at ca. 18 or 12 ml/hr <sup>↑</sup> a VPD of 110 mm <sup>commit?</sup> Hg. Excretion of salt by the salt glands apparently prevented solute concentration at the evaporating surface that would reduce transpiration. <sup>OK?</sup> Transpiration rate was reduced by high saline content only at high VPD's where other resistances in the plant may be affected by increasing transpiration rates beyond the transport capacity of the plant (Mace 1971). Wilkinson (1972) found that saltcedar cladophylls developed water potentials of -5 bars by early July and -20 bars by September when plants grew in sand with a high water table. Relative water content (RWC) of trees at a 3-ft water table was not different from trees at a 10-ft table. RWC was correlated with: season, solar radiation, air temperature, wind velocity, relative humidity, and prior growing conditions.

Saltcedar apparently reaches a maximum rate of transpiration in the late morning but somehow reduces transpiration substantially below its expected potential during the hottest part of the afternoon (van Hylckama 1969). J. E. Anderson (1977, 1982), at Bernardo, NM, site, measured the parameters that influence leaf diffusive (stomatal) resistance of saltcedar-- irradiance, temperature, and the absolute leaf-air humidity gradient. Saltcedar (*T. chinensis*) transpired a mass of water equal to its own fresh mass each hour, which was practically the same as that by cottonwood and

Russian olive. However, water use efficiency by saltcedar (the ratio of photosynthesis to transpiration) was only 52 to 65% that of the other plants. J. E. Anderson (1982) speculated that this was caused by increased respiratory costs of salt excretion, which in saltcedar is thought to be an active process (Waisel 1972). Photosynthesis was light saturated at ca. 44% of full sunlight (Fig. 28). Carbon dioxide assimilation was tightly coupled to irradiance below light saturation and dropped by 40-50% within 1-2 min. when a cloud passed. When the measurement apparatus was shaded for 5 min., transpiration resistance continued to increase for 7 min. after the shade was removed, resulting in a 37% decrease in transpiration. Transpiration did not return to normal until 25 min. after the shade was removed (J. E. Anderson 1982). Optimum leaf temperatures for photosynthesis were 23°-28°C, far below the 32°-38°C typical in the field during the study period. Photosynthesis then would be reduced by 20% or more below the maximum rate (Fig. 29). Leaf resistance increased linearly with temperature when held at constant RH (thus, the absolute leaf-air humidity gradient increased with temperature), which J. E. Anderson (1982) concluded was caused primarily by the leaf-air humidity gradient rather than by a direct effect of temperature on the stomata or plant water stress.

Diurnal patterns of water potential of excised twigs (measured in a pressure bomb) closely followed incident sunlight in the field. Transpiration leveled off after 10:30 a.m., then gradually decreased throughout the remainder of the day, even though air temperature continued to increase until mid-afternoon (Fig. 30).

Leaf resistance doubled from early morning to mid-afternoon, then increased sharply with decreasing light; maximum resistance occurred from ca. 8:30 p.m. until midnight then began decreasing. At 5:00 a.m., well

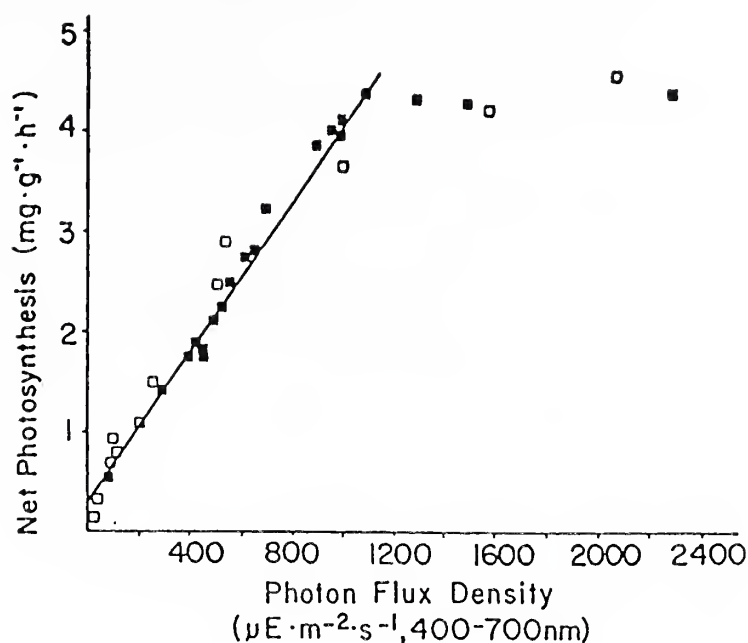


Fig. 28 Relationship between net photosynthesis and photon flux density for laboratory-grown ( $\square$ ) and field-grown ( $\blacksquare$ ) *Tamarix chinensis* plants. Photosynthesis is expressed on a basis of  $\text{CO}_2$  mass per unit leaf fresh mass per hour. Trend line is least squares fit to all points at photon flux densities  $<1200 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ . Data for field-grown plants were converted from dry mass to wet mass basis and redrawn from J. E. Anderson (1977) (from J. E. Anderson 1982, Fig. 1).

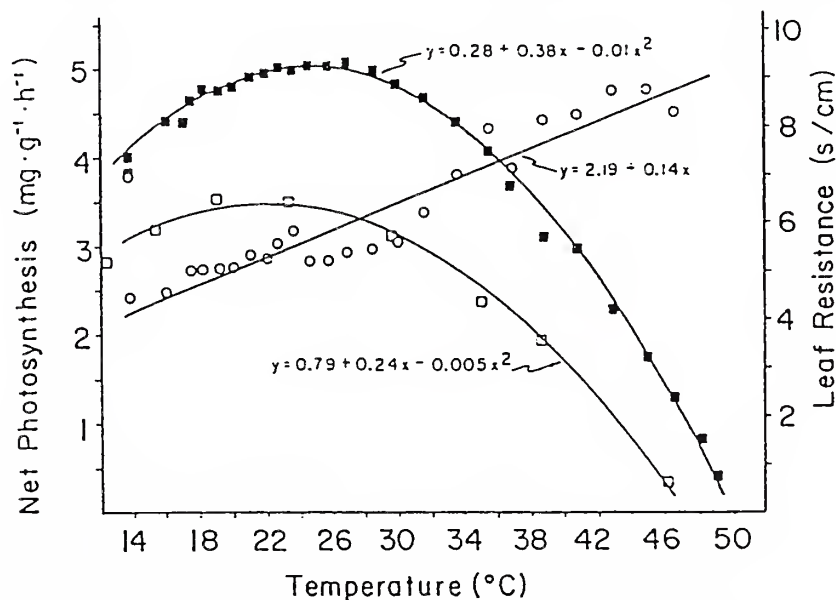


Fig. 29 Net photosynthesis of laboratory-grown ( $\square$ ) and field-grown ( $\blacksquare$ ) *Tamarix chinensis* plants, and leaf resistance of the field-grown plant ( $\circ$ ), as a function of leaf temperature. Photosynthesis is expressed on a basis of  $\text{CO}_2$  mass per unit leaf fresh mass per hour. Relative humidity was approximately 45% throughout experiments. The curves are for individual plants but are representative of several trials in both the field and laboratory. Data for field-grown plant were converted from dry mass to wet mass basis and redrawn from J. E. Anderson (1977) (from J. E. Anderson 1982, Fig. 2).

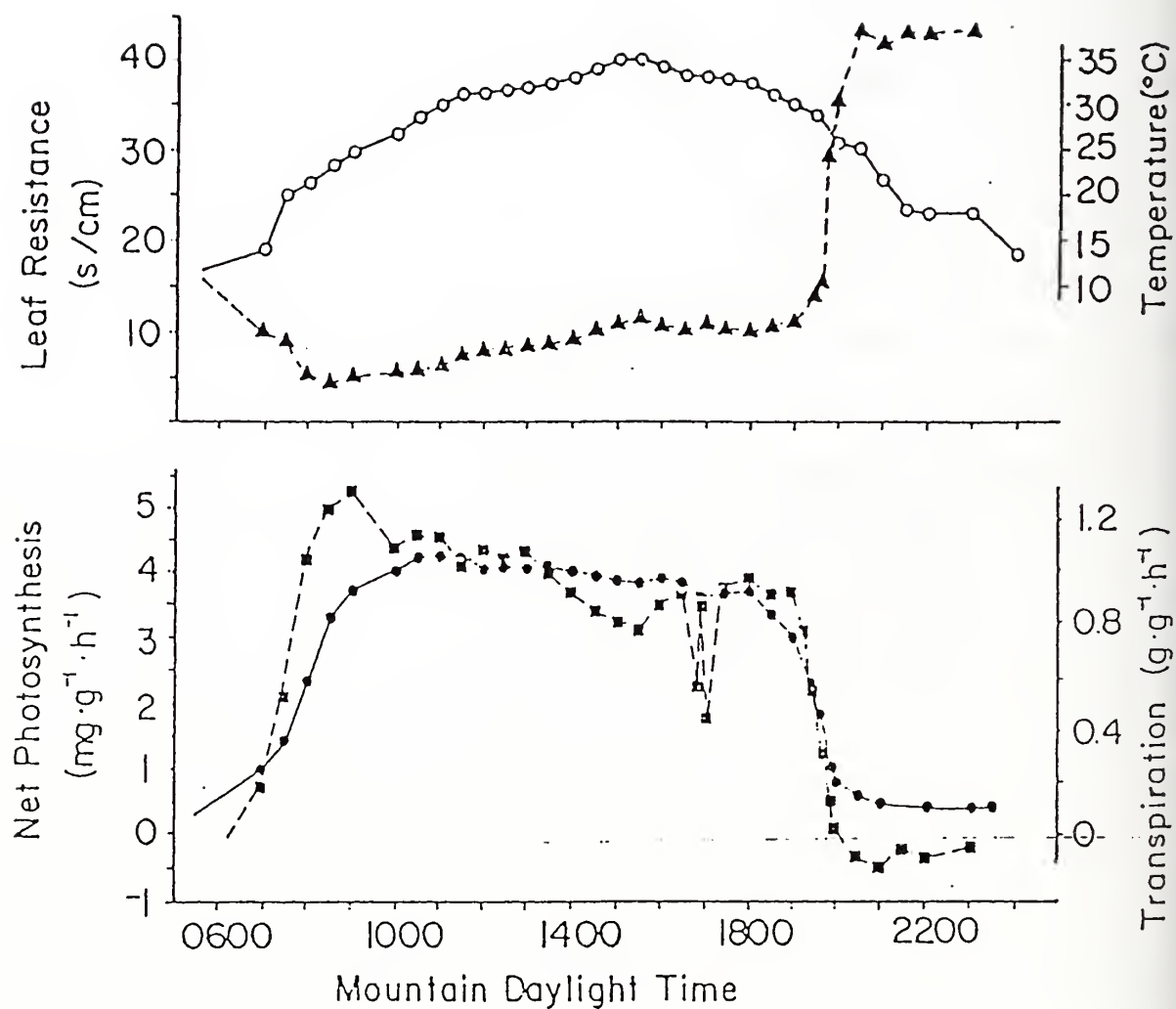


Fig. 30 Diurnal patterns of air temperature (o), leaf resistance ( $\blacktriangle$ ), net photosynthesis ( $\blacksquare$ ), and transpiration ( $\bullet$ ) for a *Tamarix chinensis* plant on a lysimeter at Bernardo, NM, June 10-11, 1976. Photosynthesis is expressed on a basis of  $\text{CO}_2$  mass per unit leaf fresh mass per hour; transpiration is expressed as  $\text{H}_2\text{O}$  mass per unit leaf fresh mass per hour (from J. E. Anderson 1982, Fig. 7).

before sunrise, resistance was less than half the maximum. Photosynthesis peaked by 9:00 a.m. when air temperature was still relatively cool, then declined because of increasing leaf resistance and air temperature. Maximum midday depression coincided with maximum air temperature; photosynthesis increased after 3:30 p.m. as the air cooled.

J. E. Anderson (1982) concluded that saltcedar has developed evolutionary adaptations to conserve moisture when light limits photosynthesis. The observed temperature optimum of 23°-28°C (well below typical midday temperatures) is surprising for a desert plant expected to adapt to high temperature. However, the optimum is within the same range as ambient temperatures in the early part of the day when evaporative demand and stomatal resistance are lowest; maximum water use efficiency would be achieved during this time. To maximize photosynthesis during the hottest part of the day would result in much higher transpirational losses relative to carbon gains.

Estimates of water usage in the field that fail to treat stomatal resistance as a variable in estimating evapotranspiration from meteorological data and stand characteristics may result in significant overestimates (J. E. Anderson 1982).

#### K. Water Usage Before and After Clearing Phreatophytes

1. Gila River Phreatophyte Project, San Carlos, AZ. By 1962, it had become obvious that the most urgent need in phreatophyte-control research was to evaluate actual water conservation on the floodplain of a major river. The U.S. Geological Survey selected a research site along a 15-mile reach of the Gila River floodplain within the San Carlos Indian Reservation of the Apache Tribe in southwestern Arizona. The site characteristics and research methods were described in detail by Culler (1965) and Culler et al.

*When was the  
last flood  
built*

(1970). The upper part (Reach 1) overlapped the lower part of the study area of Gatewood et al. (1950).

Early records indicate that during the period 1846-1904 the stream channel of the Gila River in this area was narrow and meandering, with an average width of < 150 ft in 1875 and < 300 ft in 1903; early photographs show the floodplain covered with willow, cottonwood and mesquite. From 1905 to 1917, several large floods occurred that destroyed the vegetation and widened the channel to an average 2000 ft. Saltcedar invaded and became the dominant vegetation in the 1930's; and from 1918 to 1970, the channel gradually narrowed to an average < 200 ft in 1964, and became meandering (Burkham 1972). Since 1920, annual and especially winter precipitation have consistently declined in the watershed area. In the 25 years from 1891 to 1916, 9 major floods occurred; but in the 48 years from 1917 to 1965, there was only one major flood (Burkham 1970).

For the Phreatophyte Project study, the area was divided into three 5-mile reaches of different vegetation composition. Reach 1 (upstream) contained 1673 acres, 61.7% saltcedar and 38.3% mesquite; Reach 2a contained 2257 A, 63.2% saltcedar and 36.8% mesquite; Reach 2b contained 1342 A, 48.7% saltcedar and 51.3% mesquite; and Reach 3 (downstream) contained 1438 A, 97.6% saltcedar and 2.4% mesquite. From 1964 through 1971, 5415 acres of the densest vegetation was cleared, 71% of this during 1967, 1968 and 1969. Reach 1 was cleared in 1964-67, Reach 3 (downstream) in 1968, and Reach 2 in 1969-1971 (Culler et al. 1982).

Total inflow-outflow of water within the area was estimated in a water-budget analysis. Evapotranspiration was calculated as the residual in an equation in which 12 factors were estimated:  $ET = (\text{river and tributary inflow minus river outflow}) + (\text{channel storage}) + (\text{change in soil moisture})$

at 3 levels + lateral ground-water movement) + (downvalley ground-water inflow-outflow + inflow from "basin fill") + (precipitation). Four gauging stations on the main river and 62 additional gauges on the tributaries measured river and tributary inflow and outflow. Ground-water movement and changes were calculated from a system of 74 recording wells (3 on each side of the river at each of 6 cross sections) plus 38 additional wells along the outer boundary of the floodplain that measured depth of the water table. Soil moisture was measured with a neutron probe in 72 access tubes. Precipitation was measured with 24 rain gauges (Culler et al. 1982). The characteristics of tributary inflow were reported by Burkham (1976a). *20 wks. 9 mos. 180 mos*

From these data, evapotranspiration was calculated for 414 budget periods of 2-3 weeks each from 1963 through 1971 (312 periods provided usable data). However, because of the quantities involved, small measurement errors can completely obscure evapotranspiration values. Average annual evapotranspiration was only 3% of total inflow-outflow before clearing and only 1% after clearing. Culler et al. (1982) concluded that the acceptable data were too few and too spatially and temporally variable to accurately define evapotranspiration for any individual reach in a particular year (Fig. 31). However, averaging the data by month gave an estimate of evapotranspiration before and after clearing (Fig. 32).

Culler et al. (1982) also fitted these data to four previously developed and widely used empirical equations in order to combine data from all reaches and to compensate for the spatial and temporal variability. These equations were:

- 1) Blaney-Criddle - based on monthly % of total daytime hours in the year and mean temperature,
- 2) solar radiation - expressed as inches/day evaporation equivalent,
- 3) Jensen-Haise - solar radiation and mean temperature, and
- 4) pan evaporation.

EVAPOTRANSPIRATION (ET), IN MILLIMETERS PER 30 DAYS

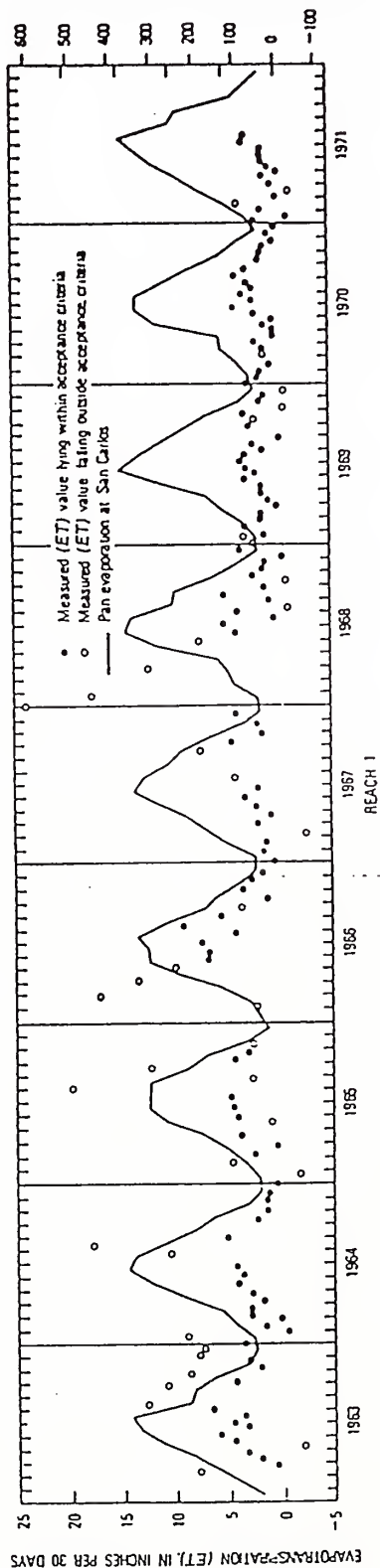


Fig. 31 Measured evapotranspiration for each budget period during 1963-71 and monthly pan evaporation at San Carlos Reservoir (from Culler et al. 1982, Fig. 7).

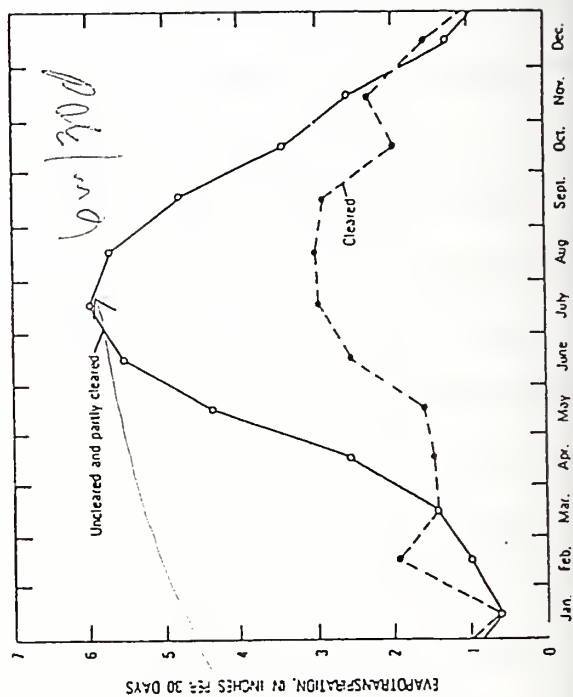


Fig. 32 Average monthly ET before and after clearing based on selected ET data from all ranches (from Culler et al. 1982, Fig. 10).

Statistical tests indicated no difference among the four equations; however, only the Blaney-Criddle and the solar radiation equations fit the seasonal pattern of plant foliation and they considered these to be the best predictors. The four estimated evapotranspiration within  $\pm 3\%$  of the mean of the four before clearing and within  $\pm 10\%$  after clearing (Table 52).

Table 52. Evapotranspiration (inches/year) as calculated by 4 empirical equations before and after clearing phreatophytes from the floodplain along a 24-mile reach of the Gila River, AZ (rainfall excluded) (from Culler et al. 1982, his Table 18).

Method	Before clearing			After clearing (mean of Reaches 1,2,3)
	Reach 1	Reach 2	Reach 3	
Blaney-Criddle	27.50	31.49	39.45	13.79
Solar radiation	27.67	31.81	39.97	12.90
Jensen & Haise	27.92	31.83	41.26	11.16
Pan evaporation	<u>26.53</u>	<u>30.50</u>	<u>38.88</u>	<u>12.07</u>
Mean	27.40	31.66	39.89	12.48
Means		32.98 (84% evm)		12.48 (31.7% evm)
% of area in <u>Tamarix</u> vs <u>Prosopis</u>	61.7-38.3	67.1-32.9	97.6-2.4	

Culler et al. (1982) calculated that average annual evapotranspiration (less precipitation) from all 3 reaches was 32.98 in. before clearing and 12.48 in. after clearing, for a difference of 20.50 in. (Culler states 19.90 in.). This gave a reduction in evapotranspiration of 61% caused by clearing. The reduction ranged from 14.9 in. in Reach 1 to 27.4 in. on Reach 3, a difference they attributed to the greater density of phreatophytes (saltcedar) on Reach 3. The water table recorded in some wells rose 0.1 to 0.2 m in midsummer from 1964 before clearing to 1969 after clearing.

Culler et al. (1982) pointed out that this reduction in evapotranspiration in the cleared area was before replacement vegetation became established. They estimated that alfalfa would use 69 in. water/yr and blue panic grass .49 in. if their roots reached the water table and if they maintained optimum production; therefore, no water would be salvaged downstream. Selective clearing of only the densest phreatophytes and conversion to blue panic or bermuda would provide a salvage of 7 in. or 14 in. from those areas. However, if consumptive use by the grasses was less than optimum (the water table exceeded 8 ft), crop production would be less and more water could be salvaged.

Hanson and Dawdy (1976) did a detailed analysis of the measurement errors for each of the 12 components of the evapotranspiration equation during each year of the Gila River Phreatophyte Project. Although the relatively small usage by phreatophytes could easily be obscured by small measurement errors in the large quantities of inflow-outflow of the river, these errors were considerably reduced because most of the stream flow was during the winter when the plants were dormant and during only a few weeks in summer after storms; during most of the growing season, river inflow-outflow was much less, and the measurement errors were correspondingly less.

During the summer, measurement errors were  $\pm 59\%$  of the computed average evapotranspiration before clearing,  $\pm 113\%$  after clearing, and the error of the change in evapotranspiration was  $\pm 200$  percent. However, after considering all the factors, they concluded that reliable estimates of evapotranspiration were obtained and that the difference in evapotranspiration before and after clearing was significant (Hanson and Dawdy 1976).

2. Pecos River Studies. Weeks et al. (1987) attempted to measure water usage by saltcedar and replacement vegetation on the Pecos River from:

Acme to Artesia, NM, during 1- to 3-day periods in October 1980, May 1981, June 1980, 1981, 1982 and late August 1982. Saltcedar sites were of 4 types: 1) old growth (10 ft water table), 2) wet old growth (2-3 ft water table), 3) burned in 1974 (4-6 ft water table), and 4) mowed in 1977 (10 ft water table). Replacement vegetation plots consisted of: 1) grass and forbs, 2) forbs, and 3) grass; all were root plowed in 1974. The area was initially cleared in 1967 by bulldozing and mowing and later in 1974 by root plowing 8700 ha (21,500 A) of the floodplain. At all sites, they measured usage by the energy budget and the eddy-correlation methods.

In the saltcedar plots, the old growth used the least water in all three years in both June and August. The mowed sites used the most water in June and near the maximum usage in August. Old wet growth used the second most water in June and the most or second most in August (depending on the method of measurement). Water usage in the burned area was intermediate (Fig. 33). They were unable to get closure in the energy budget method, which prevented measurements of the expected precision, but they were able to set minimum and maximum values. Usage by saltcedar and replacement vegetation and the difference, or "salvage," is shown in Table 53.

Table 53. Annual water use in the Pecos River floodplain (estimated range, from Weeks et al., 1987, his Table 5).

	Water usage in meter/yr (and inches/yr)		
	Saltcedar	Replacement vegetation	"Salvage"
	-----Based on energy-budget residual-----		
Maximum	1.07 (42.1)	0.67 (26.4)	0.40 (15.75)
Median	0.90 (35.4)	0.62 (24.4)	0.28 (11.02)
Minimum	0.77 (30.3)	0.57 (22.4)	0.20 ( 7.87)
	-----Based on eddy correlation-----		
Median	0.60 (23.62)	0.40 (15.75)	0.20 ( 7.87)

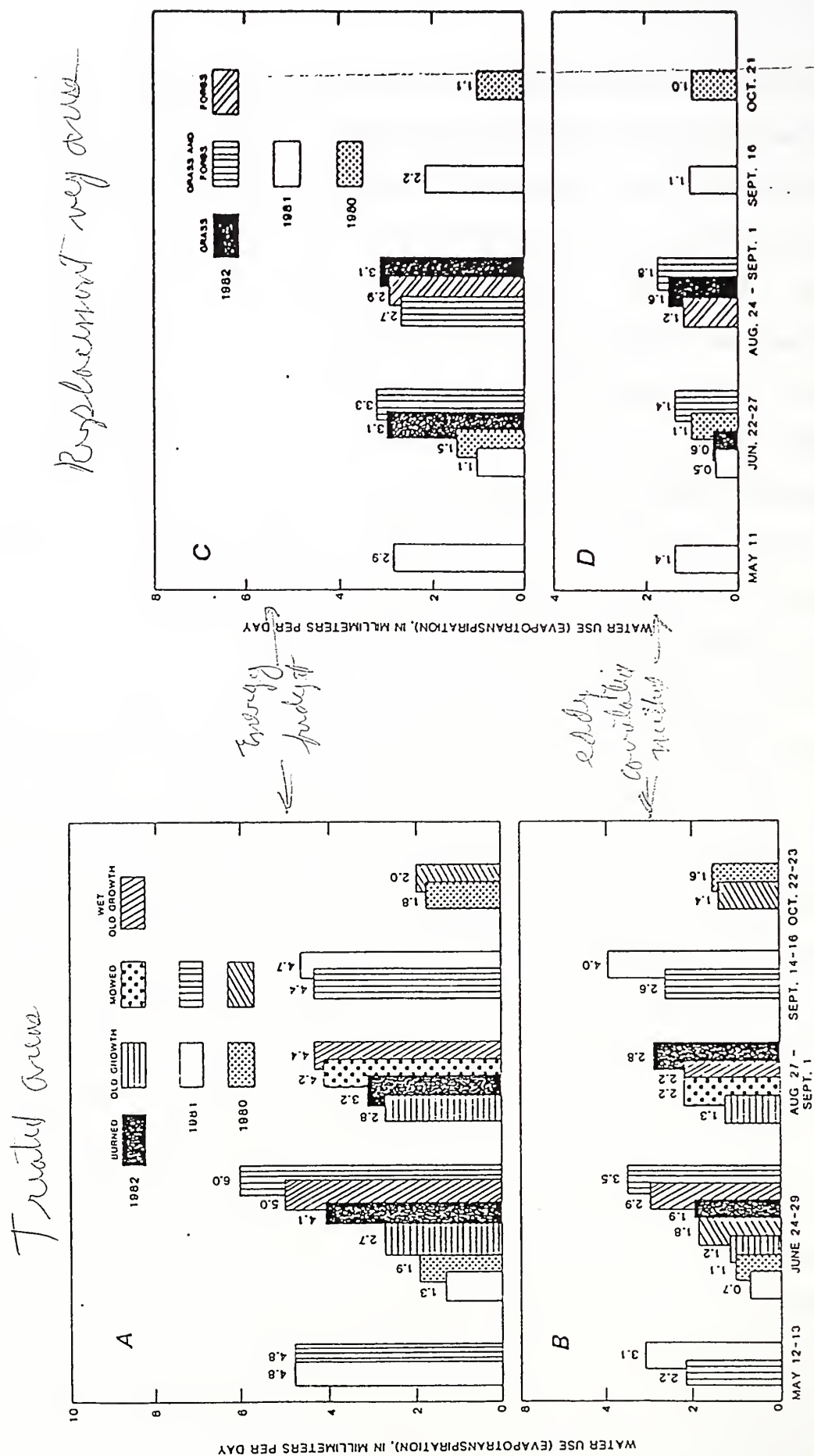


Fig. 33 Summary of estimates of daily evapotranspiration in treated areas (A & B) and replacement vegetation (C & D) by the energy-budget-residual method (A & C) and the eddy correlation method (B & D) (from Weeks et al. 1987, his Figs. 8 and 9).

Eradication of saltcedar from 21,500 acres of the Pecos River floodplain never resulted in base-flow gains that could be reliably related to the clearing. This suggested that water usage by replacement vegetation, mainly annual weeds and alkali sacaton, was about equal to that of saltcedar. Extrapolation of the results of the measurements of Weeks et al. (1987) to the entire reach of the floodplain is difficult because of variability of hydrologic and soil conditions and in the density and vigor of the saltcedar prior to clearing. However, a "salvage" of ca. 0.3 m/year, or 10,000 to 20,000 acre-ft/yr, may have occurred (Weeks et al. 1987). They speculated that variations in climate and in ground-water pumping, and from a continuing decline in the ground-water contribution to base flow from the shallow aquifer, may have masked any gains that could be measured by the stream gauges.

One could also conclude from the data of Weeks et al. (1987) that the end result of the clearing of the saltcedar was not only a destruction of wildlife habitat (although saltcedar is poor habitat it is better than the cleared areas) but also that clearing saved little water since the old growth saltcedar used only slightly more water than replacement vegetation and mowed saltcedar used much more water than the old growth saltcedar. Of course, all, or nearly all, of the water was salvaged in areas kept free of all vegetation.

3. Other Studies. Horton and Campbell (1974) and Johns (1990)<sup>89</sup> reviewed four other studies in Arizona and southern California in which researchers estimated water usage by other vegetation types (not saltcedar) on riparian reaches; some of these were with comparisons before and after removal of phreatophytes (Table 54). Horton and Campbell (1974) stated that, "Only a few estimates of evapotranspiration have been obtained from

ble 54. Summary of studies in elevation zone below 4,300 ft. with estimate of ET (evapotranspiration) per acre of flood plain (from Horton and Campbell 1974).

ach, elevation range d area	Length of channel (miles)	Dominant vegetation type	Depth (ft) to water table	Est. ET/acre of channel (acre-ft)	Savings after treatment (acre-ft)	Comments	Reference
CAMORE CREEK, AZ ,400-1760 ft) 1,400 acres	10	Mesquite- burrobrush	20 (approx.)	1.1	--	Inflow-outflow technique, vegetation not treated.	Thompson and Schumann (1963)
UA FRIA, AZ ,600-4,000 ft) 3,230 acres	61	Mesquite	0-2(36%) 5-6(22%) 10-20(42%)	1.8	--	ET est. on basis of depth to ground water and aerial density. Vegetation not treated.	Anderson (1970)
ITTONWOOD WASH, AZ ,000-4,300 ft) 22 acres	1.5	Cottonwood	2-3	3.6	1.7	Inflow-outflow technique, vegetation eradicated on one sector. Control sector above treatment area.	Bowie and Kam (1968)
INROE CANYON, SO. CAL. ,000-2,500 ft) 38 acres	1.3	Oak, maple, bigcone Douglas-fir, alder, willow		4.2- 5.0	.5	Paired watersheds, Monroe Canyon vegeta- tion treated following calibration period; Wolfe Canyon used as control watershed.	Rowe (1963)

riparian reaches, and these data, like phreatophyte water-loss data, are not necessarily transferable to other sectors . . . . Plant-species diversity (frequency, composition, and age) and highly variable environments create a situation where no completely satisfactory method has been developed."

Horton and Campbell (1974) concluded that the few riparian treatments performed indicated rather consistent increased water yields were obtained following riparian treatments. Two reach studies (Table 54) indicate a water savings of about 1.1 acre-ft per acre after removal of flood-plain vegetation. Two other studies predicted that reduction of evapotranspiration losses of about the same amount might occur if the denser vegetation on the flood plain were removed. In summary, a working hypothesis somewhere between 1 and 2 acre-ft of water savings is as close an approximation as possible with the limited data available. These water yields would have to be weighed against losses or gains from other resources such as wildlife habitat and food, fish habitat, recreation, and esthetics for evaluation of possible benefits (Campbell 1970).

#### L. Discussion, Economics, and Effects of Biological Control on Water Usage

The basis for the large amount of research and clearing activity was the seemingly obvious assumption that the water used by phreatophytic plants could be converted to agricultural, urban, or industrial use after removing these plants. In practice, the actual measurement of water usage by phreatophytes and the amount that could be salvaged for other uses, has proven to be exceedingly difficult in spite of very large experiments over several years by many of the most capable researchers.

Several intensive, large-scale experiments were conducted from the 1940's through the 1970's using a variety of different methods, but the most effort was spent and the most meaningful results were obtained from: 1) lysimeter

tanks, 2) total inflow-outflow of several-mile-long reaches of rivers, and 3) energy-budgets determined from measuring climatic parameters.

The amount of water used by saltcedar varies with the density, size and age of the plants; with depth of the water table; with atmospheric temperature, humidity and wind velocity; with salinity of the groundwater supply; with elevation above sea level; and possibly with other factors. Saltcedar uses progressively less water at greater depths to the water table, at higher salt concentrations of the groundwater, and at higher elevations. The best micrometeorological measurements are in close agreement with the better estimates from lysimeter tanks. Also, several empirical equations that use readily available climatic data agree closely with lysimeter tank measurements. Most workers implicitly would prefer to use data from the lysimeters to calibrate the other methodologies such as empirical equations, energy budgets, transpiration wells, etc. However, the lysimeter measurements also are influenced by a variety of factors, some known and some unknown, and contain errors of uncertain dimensions and directions. On the Pecos River, NM, Weeks et al. (1987), attempted to measure water usage in the field before and after clearing saltcedar, using the energy budget method but they were unable to obtain closure of the energy budget.

One method that could give absolute measurements of water usage in a watershed in the field is the inflow-outflow method. This was investigated intensively on the Gila River, AZ, over a several year period during the 1960's both before and after clearing saltcedar (Culter et al. 1982). These experiments were not completely successful either, primarily because the small errors in measurement of the large inflow and outflow volumes masked the relatively small evapotranspiration quantities, which were the residual of inflow less outflow.

Estimates of water usage over large areas is greatly hampered by incomplete estimates of the area infested by saltcedar and the size and density of the plants within the infested areas. Surveys of infested areas using the computer-assisted remote sensing techniques developed during this study (see Appendix II, this report) could solve this problem. Also, depth to the water table is not known except in the few small study sites. Published, area-wide water table depths are in 20 ft contours which is too coarse for measuring water usage by phreatophytes.

These various studies were somewhat inconclusive. A comparison of the same locations over time was not possible because of time-related differences in precipitation, water flow, and other factors. Also, it was not possible to compare different areas at the same time because of spatial differences in the same factors. In fact, no absolute standard is available for calibrating any of the methods and the best that can be produced to date is that several methods that appear theoretically reasonable are in agreement with each other. Extrapolation of these methods to conditions in nature adds additional factors of uncertainty.

Estimates of usage at different locations and at different depths of the water table vary from 10 ft/yr with fresh water at a 5-ft water table at a low elevation to 3 ft/yr at higher elevations and deeper water tables (Fig. 34). Johns (1990) also summarized the data from experiments at Safford, AZ (Gatewood et al. 1950), Buckeye, AZ (van Hylckama 1974), Graham Co., AZ (Culler et al. 1982) and Blythe, CA (Gay and Hartman 1982) from which he obtained 27 data points relating water usage by saltcedar to depth to groundwater at depths of from 4 to 9 ft (Fig. 35). He concluded that water use by saltcedar ranged between 3.0 and 7.5 ft depending on depth to ground water and would most likely average 4.0 to 4.5 ft over an entire

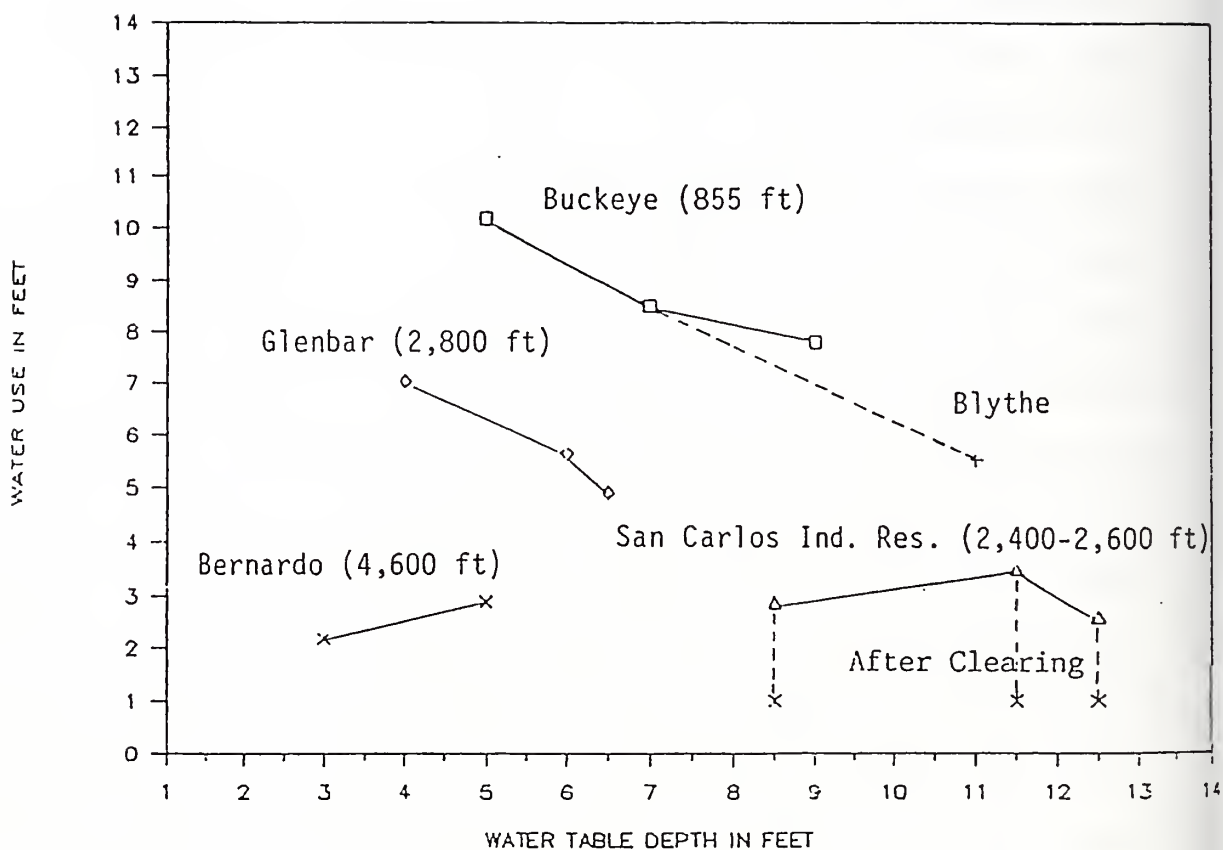


Fig. 34 Annual water use by saltcedar obtained by various workers; Glenbar (at Safford, AZ) by Gatewood et al. (1950); Buckeye, AZ, by van Hylckama (1980a and other papers); Bernardo, NM, by Bur. Reclam. (1972, 1973); south of Blythe, CA, by Gay (1985 and other papers); San Carlos Indian Reservation, AZ, by Culler et al. (1982); elevation above sea level of each location in feet. Graphical representation prepared by Jerome Horton in Brown (1989, his Fig. 2.3).

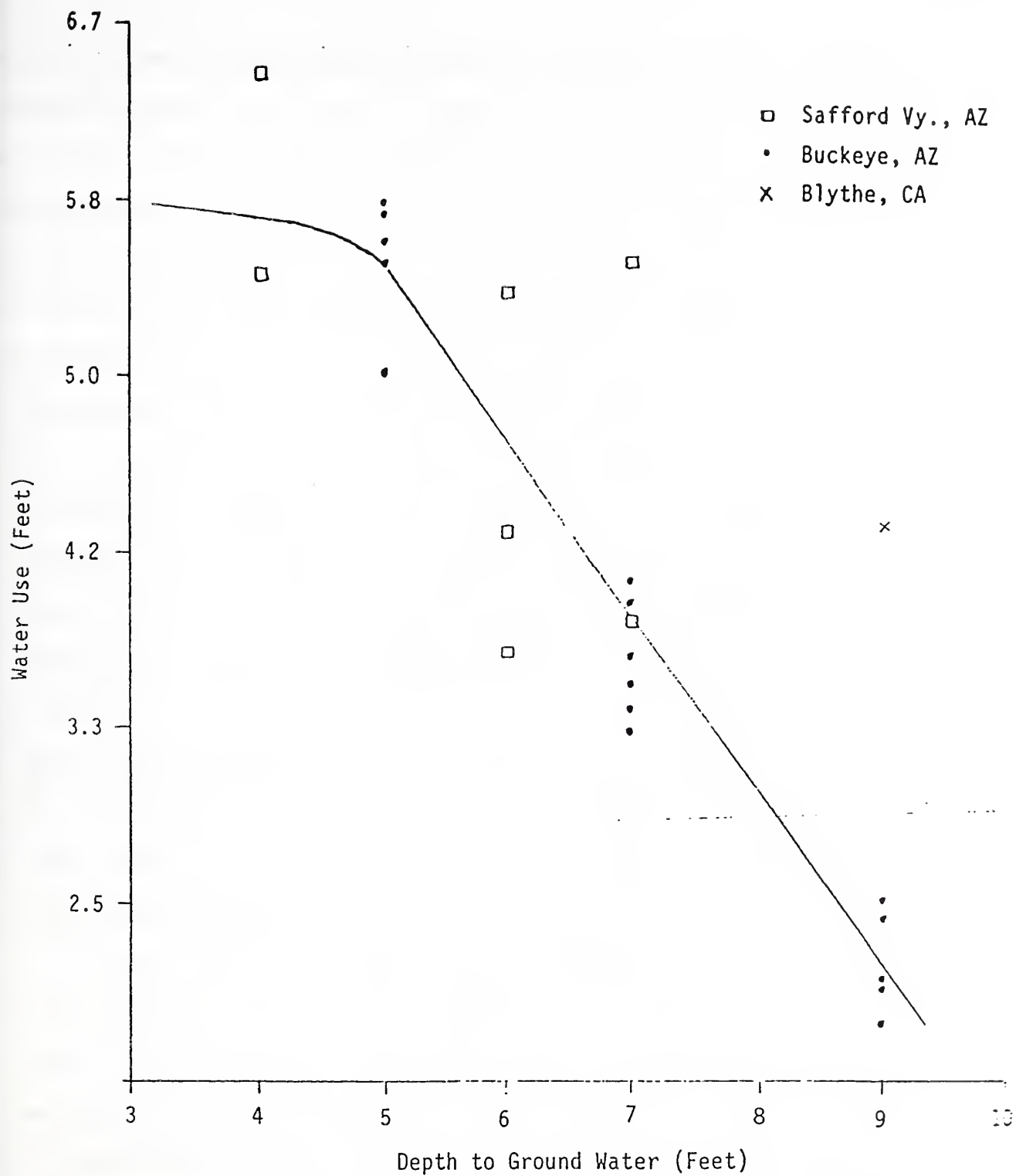


Fig. 35 Relationship of water use by saltcedar to depth of groundwater from 4 large field experiments (from Johns 1990).

floodplain. This is probably the best conclusion on water usage by saltcedar that can be drawn from the great amount of research that has been conducted.

The best estimates available of water salvage are of 19.9 in. per year obtained by clearing saltcedar (without revegetation) on the Gila River (Culler et al. 1982). A difference of 7.9 to 15.8 in per year was obtained on the Pecos River (with replacement vegetation) (Weeks et al. 1987). Johns (1990) reached a similar conclusion, that based on the more reliable studies and the fact that salvage projects are not likely to be maintained as well as anticipated, the most realistic range of water salvage will average between 1.0 and 1.5 ft. The exact values will depend on the water use by the replacement vegetation and the depth to ground water. Based on the findings of McQueen and Miller (1972), ground water levels should be at least 2.6 m from the surface to insure minimal effect from capillary flow and other factors.

Early lysimeter studies showed that seepwillow *baccharis* used 65%, cottonwood 83% and mesquite used only 46% as much water as saltcedar (Gatewood et al. 1950). If this relationships holds true under field conditions, then this more desirable vegetation (for wildlife habitat) could be used to replace saltcedar and still obtain a savings in water.

On the Pecos River, the replacement vegetation used (Weeks et al. 1987) was grass and forbs, not the cottonwood-willow which would be the ideal wildlife habitat but which would use more water. Revegetation studies on the Lower Colorado River that promised to reduce water usage, reduce flooding and provide good quality wildlife habitat (Anderson and Ohmart 1982b, Pinkney 1990) (see Sect. IV,D,2) has been, to date, only minimally successful. Revegetation at the Bosque del Apache National Wildlife Refuge

on the Rio Grande, NM, has been successful but water salvage has not been measured there.

As a part of the present study, but contracted separately by the Bureau of Reclamation's Yuma Project Office, Brown (1989) (assisted by Jerome Horton) conducted an economic analysis of water usage. They calculated water usage based on the best available (though incomplete) data discussed above relating to plant density, elevation above sea level, depth to water table, and area infested. They presented an assumed non-linear relationship of water usage to saltcedar density based on the data of van Hylckama (1974) that showed a 15% reduction in usage at 50% density compared with 100% density (Fig. 36). Then, using the curves of water usage at different water table depths for different elevations (Fig. 34), they calculated annual water usage from their estimates of plant density, water table depth, area infested, and the known elevation of each infested river. They estimated that the approximately 1.0 million acres of saltcedar in the study area consumed 2.6 million acre-feet annually. Of this total, 41% was in Texas, 26% in Arizona, 10% in Oklahoma, and 6% in New Mexico and the rest in 17 other western states (Brown 1989).

Brown (1989) further assumed that replacement vegetation would be arrowweed and/or saltbush-mesquite woodland in the lower Colorado, Salt-Gila, Pecos and Rio Grande River valleys and that it would be willow and/or cottonwood-mixed deciduous trees in other areas; this vegetation would use 3 to 5 feet of water/year. Also, evaporation from bare soil was estimated at 1.0 to 1.5 ft/yr. From these assumptions, they calculated that if a biological control program were to reduce the saltcedar infestation by 50% (reducing water usage by only 15%), water consumption would be reduced by only a small amount which they could not quantify, after usage by replacement

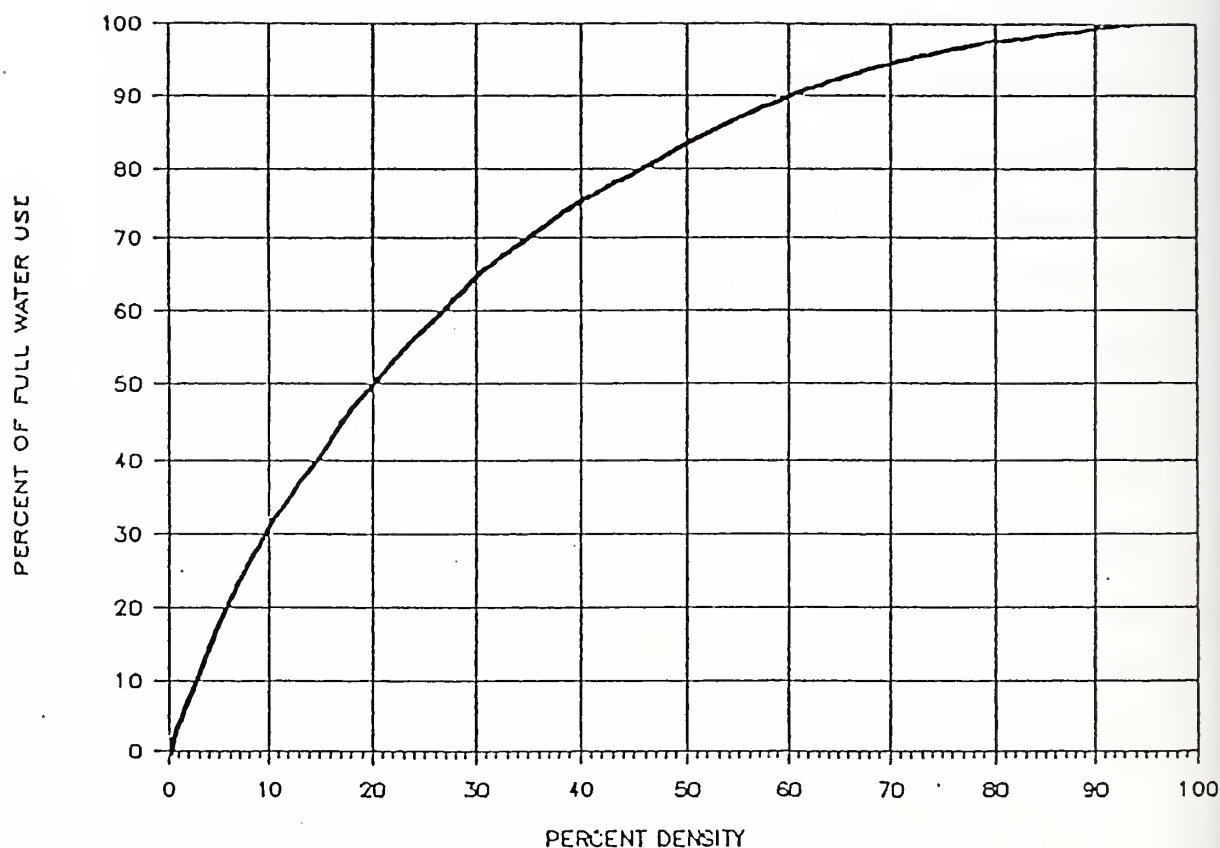


Fig. 36 Hypothetical use of water by saltcedar growing at different percentages of 100% volume-density. Only one point is known experimentally: that water usage at 50% volume-density is 85 to 90% that at 100% volume-density as determined by van Hylckama (1974) (from Brown 1989, his Fig. 2.2).

vegetation and evaporation were included. However, if a biocontrol program could reduce saltcedar infestations by 90% (reducing water usage by 70%), water consumption by saltcedar would be reduced by 1.37 million A-ft/yr. Subtracting 900,000 A-ft/yr used by replacement vegetation would leave a net difference of 475,000 A-ft/yr that potentially could be salvaged (Brown 1989).

The value of the salvaged water depends upon the use made of it. The value for agricultural usage varies from \$15 to 30 per acre foot and for municipal or industrial (M-I) usage from \$90 to 150 per acre foot. Brown (1989) estimated the total annual value of the salvageable water as follows:

<u>Area</u>	<u>Acre-feet/yr salvageable</u>	<u>Use-value/ acre foot</u>	<u>Total annual value of water salvaged (million)</u>
Lower Colorado (mostly AZ)	250,000	M-I (\$120)	\$30.0
Southwest (NM, TX, OK)	182,000	Agric (\$23.50)	4.3
Higher elevations (CO, ID, KN, NE, NV)	43,000	Agric (\$23.50)	<u>1.0</u>
TOTAL			\$35.3

## IX. SEDIMENTATION, FLOODING AND SOIL SALINITY

### A. Sedimentation and Flooding

When floods occur, dense saltcedar vegetation reduces the velocity of the water which increases the height (stage) of floodwaters and increases sediment fallout. One of the most obvious effects of saltcedar is that sedimentation increases and stream channels narrow and become clogged with debris. Sediment accretion occurs by the development of islands, deposition in the stream channel along banks, by formation of natural levees, by deposition on alluvial fans, and by direct deposition on the flood plain when flow overtops banks. The latter is aided by the retarding action of vegetation along the banks. Subsequent floodflows are impeded even more by the narrowed channel and flooding is further increased in height and covers a larger area because of the sediment previously deposited. Sediment accretion has two aspects: 1) sediment that builds up in the channel or in the floodplain causes increased flooding and channel maintenance costs, but if the sediment stays in the channel or is moved to outside the floodplain, downstream reservoir capacity is maintained, and 2) channels that move sediment efficiently and reduce flooding result in rapid sediment buildup in reservoirs and reduced water-holding capacity.

Burkham (1976b) reported that clearing saltcedar on an 18.5 km (11.5 mile) reach of the Gila River caused a 25% increase in mean velocity, a 15% decrease in mean depth, and a 30% decrease in the Manning roughness coefficient at peak stage in floods of 1967 and 1972 compared with a flood in 1965 before clearing. The first flood occurred in December 1965, had a peak flow of 39,000 cu ft/second (cfs) and the bottomland vegetation was dormant during this event. The second flood occurred in August 1967 with a peak discharge

of 40,000 cfs. The bottomland vegetation in the upper half of the reach had been cleared 5 months prior to the 1967 flood. Compared to the 1965 flood, the large amounts of foliage in the uncleared half of the reach during the 1967 flood apparently caused a 7% decrease in mean velocity, a 6% increase in mean depth, and an 11% increase in the Manning roughness coefficient at peak stage. Compared with the 1965 flood, the clearing of part of the reach apparently caused a 25% increase in mean velocity, a 15% decrease in mean depth, and a 30% decrease in the Manning roughness coefficient at peak stage in the 1967 and 1972 floods (Burkham 1976b).

The delta area above Lake McMillan on the Pecos River, NM, has become so sedimented and overgrown with saltcedar that the river has ceased to exist as a recognizable channel. Instead, it flows through numerous small, meandering streams until it reaches the reservoir. Several feet of silt have been deposited as a result of saltcedar growth (Robinson 1958). Eakin and Brown (1939) attributed the marked decrease in silting of the reservoir since 1915 to the deposition in the delta above caused by saltcedar. The first saltcedar seedlings were found in the mud flats in 1912. By 1915, saltcedar covered 600 acres, by 1939, 9,800 acres and by 1950, 10,160 acres. Deposition of silt into the reservoir was as follows (Eakin and Brown 1939):

	Deposits/yr (acre-ft)
1894-1904	1,730
1904-1910	1,560
1910-1915	2,920
1915-1925	350
1925-1932	215

The history of flooding, vegetation changes and channel structure has been well documented on the Gila River, AZ, ~~between Safford and San Carlos~~ reservoir (Burkham 1970, 1972, 1976a, b; Turner 1974) (see Section IV,A,2;

and Section VI, K, 1 and 4 of this report). Before 1875, the river was less than 150 ft wide and 10 ft deep at bankful stage and meandered through a flood plain covered with willow, cottonwood and mesquite (Burkham 1972). A major flood in 1891 and two major floods in 1905 and 1906 (8 floods during 1905-17) widened the channel to 2,000 ft, washing out over 2,100 acres of vegetation. By 1935, average width had decreased to ca. 500 ft and by 1964, to less than 200 ft. Average sinuosity of the 3 subreaches of the channel increased from ca. 1.03 in 1914 to 1.19 in 1957, increasing the length of the 39-mile river mile study reach by 6.5 miles. From 1935-70, the annual change in altitude of the bottomland by sediment deposition was 0.03 ft/yr in subreach A and 0.08 ft/yr in subreach B, or a total of 1.05 and 2.80 ft, respectively. The dense cover of saltcedar may have been a significant factor in this rapid accretion within the floodplain (Burkham 1972).

Floatable debris--mainly logs--carried by floodflows has been deposited in the channel owing to the screening effect of the saltcedar, resulting in a plugged channel; additional sediments were then deposited in the log jam. The process of channel plugging and filling progressed rapidly once log jamming started. No jamming or change in channel location was seen in aerial photos from 1935 to 1962. A log jam was first seen 1-1/2 miles above the mouth of the San Carlos River in January 1963. During summer flows of 1963 and 1964, the jam progressed upstream 3.0 and 5.5 miles (Culler et al. 1970).

The major reason for the sedimentation, channel narrowing and channel plugging is probably the invasion by saltcedar, although other factors played contributory roles. Saltcedar invaded the Gila River Valley during the 1920's and reached its maximum areal extent in 1945-55 after which farmers began clearing it for crops. Grazing by livestock began in the watershed about 1872, and by 1890 the area was severely overstocked. However, since

1905 cattle numbers have been much less and overgrazing contributed little to later floods (Burkham 1972). The Gila River watershed has sustained a fluctuating decline in annual precipitation and an almost continued decline in annual runoff since 1920, the decrease being mostly in the winter. Although nine major floods occurred from 1891 to 1916, only one (in December 1965) has occurred since 1917 (Burkham 1970).

Busby and Schuster (1971, 1973) documented the invasion of saltcedar along the Brazos River, TX, above Possum Kingdom Lake and the consequent narrowing of that channel (see Section IV,A,4). From 1940 to 1969, the distance from a point in the river channel to the first occurrence of the plant community decreased greatly for saltcedar but little for mesquite as follows (Busby and Schuster 1973):

	<u>Distance to nearest vegetation (feet)</u>		
	<u>1940</u> <u>photos</u>	<u>1950</u> <u>photos</u>	<u>1969</u> <u>photos</u>
Light saltcedar	306	62	0
Dense saltcedar	364	178	44
Mesquite	739	697	691

The area of river channel also showed a marked decrease as follows:

	<u>1940</u>	<u>1950</u>	<u>1969</u>
Area of river channel (acres)	5,080	3,806	3,808

Since the length remained constant, this corresponds to a 25% reduction in channel width.

#### B. Economic Effects of Saltcedar Control on Flooding

Brown (1989), as a part of the present study on the feasibility of biological control of saltcedar, conducted an economic analysis of the present baseline damages from flooding and the reduction in damage that would accrue if biological control were to reduce saltcedar infestations by 50% or by 90%.

They used flood data for the Rio Grande River, NM, between San Acacia and Elephant Butte Reservoir and for the Lower Colorado River above Imperial Dam. Data on channel structure and stream flow were provided by the U.S. Army Corps of Engineers in Albuquerque, NM, from the Bur. Reclam. (1972, 1973) and from the U.S. Geological Survey, Albuquerque, NM. They calculated the expected area flooded and damage expected by floods of various intensities and frequencies, based on past experience in these areas. They then calculated damages expected with either 50% or 90% saltcedar control, based on a control program that required 10 years to implement and whose value continued to the 20th year, and using an 8% discount rate (Table 55).

Table 55. Projected damage caused by flooding and benefits from biological control of saltcedar on two river systems (from Brown 1989).

	Value (in \$ million)	
	Rio Grande, NM	Colorado, CA-AZ
Present baseline conditions	98.2	9.3
Annual equivalent value	10.0	0.95
<u>50% control</u>		
Present value	81.7	8.3
Annual equivalent value	8.3	0.846
Annual benefit from control	1.7	0.104
<u>90% control</u>		
Present value	68.5	7.2
Annual equivalent value	7.0	0.729
Annual benefit from control	3.0	0.221

Brown (1989) then extrapolated these values to other major river systems invaded by saltcedar. He obtained an estimated annual value of damage prevented by saltcedar control for the entire western United States of:

50% control	\$23.0 million
90% control	\$39.8 million

### C. Economic Effects of Saltcedar Control on Sedimentation

Brown (1989) made an economic analysis of the effects of sedimentation similar to that made for flooding. In this case, the effects of reducing saltcedar infestation by biological control would be negative. This is because controlling saltcedar would increase the velocity of flood flows, thereby reducing the sediment drop-out upstream. This sediment would then be deposited in greater amounts in reservoirs. This would result in either 1) displaced storage capacity of the reservoir, 2) cost for removal of the sediment by dredging, or 3) replacement of the facility earlier than planned.

Again, Brown (1989) calculated the costs for this increased sedimentation of reservoirs for Elephant Butte Reservoir on the Rio Grande, NM, and for Imperial Reservoir on the Colorado River upstream from Yuma, AZ. Calculations were made for baseline conditions (1964-1987 at Elephant Butte and 1972-1979 at Imperial) and for 50% and 90% saltcedar control. The positive aspects of reduced sedimentation upstream from reservoirs were included in the analysis of the benefits of reduced flooding, discussed above.

Brown (1989) found that the harm caused to reservoirs by increased sedimentation if saltcedar were controlled was surprisingly small. At Elephant Butte, the cost of increased sedimentation was assumed to be equal to the value of the water displaced. In this area, the water is used both for agricultural irrigation at \$10/A ft and for power production at \$20/A ft, for a combined value of \$30/A ft. At Elephant Butte, the increased cost due to saltcedar control was \$2,600/yr for 50% saltcedar control and \$4,100/yr for 90% control (Table 56). The situation was different at Imperial Reservoir because the reservoir had already reached its sediment capacity and additional sedimentation must be continually removed at an annual average cost of \$2,582,800. Therefore, the cost of increased sedimentation was assumed

to be equal to the cost of removal, or \$1.00/cu yd = \$2.20/ton = \$4,840/A ft. The increased cost due to saltcedar control was calculated at \$78,600/yr for 50% control and \$128,600/yr for 90% control (Table 56).

Table 56. Costs of increased sedimentation of reservoirs resulting from projected 50% or 90% control of saltcedar (from Brown 1989).

	Rio Grande, NM (Elephant Butte)	Colorado, CA-AZ (Imperial)
<u>Baseline conditions</u>		
Sediment inflow	2,740 A ft	534/A ft
Cost of removing sediment	--	\$2,582,800
Present value	\$807,000	
Average annual costs	\$ 82,200	
<u>50% Saltcedar control</u>		
Sediment inflow	2,870 A ft	558/A ft
Cost of removing sediment	--	\$2,661,400
Present value	\$832,500	
Average annual costs	<u>\$ 84,800</u>	
Diff. from baseline	\$ 2,600	<u>\$ 78,600</u>
<u>90% Saltcedar control</u>		
Sediment inflow	2,950/A ft	574/A ft
Cost of removing sediment	--	\$2,711,400
Present value	\$847,700	
Average annual value	<u>\$ 86,300</u>	
Diff. from baseline	\$ 4,100	<u>\$ 128,600</u>

Brown (1989) calculated the increased losses from increased sedimentation of reservoirs caused by biological control of saltcedar for the entire Lower Colorado River (CA and AZ) and the Rio Grande and Pecos Rivers (NM and TX) to be:

50% control	\$ 500,000/yr
90% control	\$1,000,000/yr

#### D. Soil Salinity

Increased soil salinity is a complex process that is partially influenced by saltcedar. Soil salinity has increased in part because control of flood flows by dams on many rivers has eliminated the high spring flows that

leached accumulated salts from the soil. The increasing salinity level then gives saltcedar a competitive advantage because it tolerates a higher salinity level than most plants. Saltcedar contributes to the problem by excreting salt through its leaves, which then accumulates in a layer on the soil surface, preventing germination of almost all plants.

Some areas <sup>originally</sup> mostly devoid of <sup>trees</sup> vegetation (~~at least of trees~~) may have been invaded originally because saltcedar was the only plant with a nearby seed source that could tolerate the salinity levels. Recent research has developed methodologies for revegetating saltcedar-cleared areas and plants have been identified that will grow at increasingly high salinity levels, up to above 10,000 ppm. However, attempts to revegetate some cleared areas on the Gila River, AZ, with forage grasses were unsuccessful, primarily because of the high soil salinity of the area (see Sect. <sup>VI</sup> IV, D, 2).

done - Mark & Peter 1982

# X. LIVESTOCK FORAGE: COMPETITION FROM SALT CEDAR

Little information was found during the present review of literature relative to the value of livestock grazing lands lost to competition by saltcedar or to the methodology and costs of reclaiming these areas. Dense saltcedar thickets typically contain almost no plants of value for grazing by livestock (or of wildlife) because of the dense shade beneath the saltcedar canopy, the layer of salt on the soil surface produced by excretion of the saltcedar leaves and by leaf fall, and possibly by competition for soil moisture by the saltcedar roots. Livestock eat little of the mature saltcedar foliage both because of its <sup>un</sup>palatability and its height above ground, although they feed substantially on young saltcedar growth following mowing or burning.

Near the Salt River, east of Granite Reef Diversion Dam, AZ, Gary (1960) cut saltcedar stems at 6 in. above the ground in May and weighed the sprouts monthly June-October. Cattle grazed the new sprouts substantially as long as they could reach them. Sprouts in the area with cattle averaged only 40-60% as much dry biomass as sprouts excluded from grazing. In the same area, Campbell (1966) measured growth of saltcedar sprouts after different intervals of clipping, with the following results:

<u>Clipping interval</u>	<u>Sprout length (ft)</u>	<u>Sprout dry cut wt (g)</u>	<u>Mortality (1 yr)</u>	<u>Mortality (2 yr)</u>	<u>Carbohydrate reserves (roots)</u>
2-wk	0.67	4	92%	100%	20.3
4-wk	1.74	17	82%	94%	23.0
8-wk	3.57	103	39%	50%	19.0
24-wk	9.58	1,556	0%	0%	--
Control	--	--	--	--	30.5

He concluded that if saltcedar was mowed at prescribed intervals, then bermudagrass and saltcedar sprouts would produce a substantial amount of livestock forage. Increasing frequency of clipping killed an increasing percentage of the plants, especially after 2 years, but mowing killed no plants after one year. Carbohydrate reserves in the roots were decreased by ca. one-third by clipping and by one-sixth by mowing.

On the Pecos River of southern New Mexico and western Texas, Hildebrandt and Ohmart (1982) (their tables 39-41) attempted to measure grass production at 6 geographically separated sites in areas with saltcedar or where saltcedar had been cleared, with grazed and ungrazed plots in both types of areas. Yield of grass clippings was 79% greater in ungrazed than in grazed plots but was only 5% greater in cleared than in the saltcedar plots. However, differences between treatments did not even approach statistical significance because of great differences between locations and within plots, and because the samples were too few and too small. They did not describe the density or size of the saltcedar plants within the "saltcedar" treatment area. However, in their transect studies, Hildebrandt and Ohmart (1982) (their Table 4) found that ground cover of grasses, forbs and annuals averaged only 22.1% in 5 saltcedar C/S types and 35.4% in 4 C/S types of cottonwood-willow and honey mesquite, or 60% more in these latter types.

In moderate or light stands of saltcedar, forage production is possibly reduced in relation to the degree of cover of the saltcedar canopy. Also, dense thickets increase management costs by limiting the visibility of livestock. The extent to which this potential resource is shared by livestock or wildlife was not determined in the present study. The apportionment of riparian areas has been a subject of intense debate between livestock producers and wildlife supporters for several years.

Little information was found that described the amount of increased forage or livestock production on lands cleared of saltcedar. Hildebrandt and Ohmart (1982) designed a statistical sample to test forage production on lands cleared and not cleared of saltcedar in the Middle Pecos River Valley where forage was clipped, dried and weighed. Although cleared areas had been largely replaced by alkali sacaton and other less abundant grasses, along with forbs and shrubs, the sampling was too limited to confirm significant differences.

In another instance, cleared areas along the Middle Rio Grande River in New Mexico were revegetated with saltgrass and cattle grazing was practiced on these lands (Schembera, pers. comm., 1972, cited in Brown 1989). Grazing also helps to control new saltcedar invasions because cattle will eat the young tamarisk sprouts as well as the available grasses in the browsing area.

Several experimental plot studies have been conducted to determine which species are most suitable for revegetation under different climatic conditions (Soil Conservation Service-USDA 1953, 1964, 1965; Powers and Hamilton 1961; Hildebrandt and Ohmart 1982). The most successful grasses at lower elevations in the Southwest were found to be bermuda, blue panic and saltgrass. At higher elevations, tall wheatgrass, alkali sacaton and saltgrass were several of the more successful species Brown (1989).

The success of revegetation depends upon the salinity of the soil, timely rainfall or irrigation, soil moisture and depth to the water table, and predation of seeds by insects, rodents and birds. Experimental revegetation plots on the Gila River failed because of high soil salinity (Mace et al. 1966) as described above (see Sect. IV,D,2).

Brown (1989) attempted to analyze the value of saltcedar infested lands for livestock forage. He divided the infested area into two general areas:

1) a drier southern area (TX, OK, NM, NV) where saltgrass was a representative species for revegetation, and 2) a northern, higher area with greater precipitation (CO, KN, NE, UT, WY, MT, ID) where wheatgrass was a representative grass. The area in saltcedar was:

	<u>Medium canopy (acres)</u>	<u>Dense canopy (acres)</u>
Southern (saltgrass)	150,198	123,505
Northern (wheatgrass)	43,510	32,910

His analysis assumed an average lease value for grazing of \$4.00/animal unit month (AUM) in the saltgrass area and \$1.86/AUM in the wheatgrass area. He also assumed that control would last 20 years, that conversion <sup>from</sup> for saltcedar to grass would occur uniformly over the first 10 years, and an 8% interest rate. The cost of artificial seeding was assumed to be \$15/acre. This additional investment in artificial seeding over natural seeding was assumed to double production, from 0.5 AUM to 1.0 AUM in the saltgrass area and from 0.75 AUM to 1.50 AUM in the wheatgrass area.

Brown (1989) then calculated values for both natural and artificial reseeding under regimes of 50% or 90% saltcedar control. Total annual benefits over the 20-year treatment horizon were as follows (Brown 1989, Talbe 3.3):

	<u>Natural</u>	<u>Artificial</u>
50% control	\$234,500	\$270,500
90% control	424,800	490,600

Obviously, many uncertainties exist in these estimates because of the scarcity of data, particularly regarding expected success in establishing grasses, and the survival, growth and production expected from them. Given the many uncertainties, these estimates are probably as good as any that could be made at present.

## XI. OTHER HARMFUL VALUES

Dense saltcedar stands are undesirable in campgrounds and recreational areas because of the unpleasant exudation of salt from the foliage, especially on warm mornings (Horton and Campbell 1974), because they block access to and the view from recreational areas, block air flow, increase problems from mosquitoes and other noxious insects, increase dust, fire hazard and hazards to boats, and produce less shade than other trees. The invasion and displacement of native vegetation is contrary to the objectives of the National Park Service to maintain wilderness areas in their natural state (see Sect. VI,E).

## XII. VALUE FOR HONEYBEES

Honeybees are a valuable part of the U.S. agricultural economy, for production of both honey and beeswax but more importantly, for pollination of crops. The United States ranks third worldwide in honey production with 205.0 million pounds, behind the USSR with 418.9 and China with 220.5 million pounds. Mexico ranks fourth, with 141.1 million pounds (1983) values. Honey production in 1981 in the Southwest that would be influenced by the abundance of Tamarix is shown in Table 57.

Table 57. Honey and beeswax production in the southwestern United States (from Economic Research Service-USDA 1984).

Area	No. colonies X1000	Honey yield/ colony (lb)	Production (1000 lb)	
			Honey	Beeswax
Arizona	64	53	3,392	1,825
Colorado	41	62	2,542	61
New Mexico	18	39	702	0,38
Texas	190	60	11,400	239
Utah	46	37	1,702	41
Wyoming	44	72	3,168	67
TOTAL U.S.	4,213	44	185,927	3,712
Mexico			132,300	
World			2,003,400	

In Arizona, commercial honey production takes place mainly in irrigated river valleys, especially the Salt, Gila, Santa Cruz, and Colorado. Most beekeepers move their colonies at least once during the season to follow pollen and nectar flow (Waller and Schmalzel 1976).

In the early spring, beekeepers get colony buildup from pollen producing plants such as cottonwood (Feb.) and winter annuals such as London rocket and bladderpod (Cruciferae), filaree (Erodium) and Phacelia. The first surplus

of honey is obtained in March from citrus, especially near Yuma and Phoenix. Next, beekeepers attempt to obtain a desert crop, primarily from mesquite, catclaw (Acacia), paloverde (Cercidum), saltcedar, arrowweed, creosotebush, ironwood, and saguaro cactus. The desert flow may be heavy and of long duration or may be light, depending on rainfall. A second crop is often obtained from mesquite (Waller and Schmalzel 1976).

In summer, the major production is from agricultural crops, especially alfalfa, cotton and safflower. Production from cotton, though of excellent quality and volume, is risky because poorly-timed insecticide applications may kill the bees.

In autumn, there is often good flying weather but little forage for the bees, conditions that induce the bees to rob other colonies. Pollen and honey sources during the period are seepwillow and desert broom (both Baccharis), burrowweed (Haplopappus), wild buckwheat (Eriogonum), athel, and saltcedar.

In Arizona, bees are active and produce broods throughout the winter except during extremely cold periods. Eucalyptus blooms throughout the winter in several locations, as do several winter annuals.

The major emphasis in Arizona is on honey production, but beekeepers also supply bees to pollinate several crops, especially cantaloupe, watermelon, other melons; seed alfalfa, onion and carrots; pickling cucumbers; and, occasionally, cotton and fruit trees (Waller and Schmalzel 1976).

Near Tucson, AZ, in an area of natural desert vegetation with little saltcedar present, various species of Compositae, mesquite, creosotebush and Heterotheca made the greatest contribution to the annual pollen harvest of honeybees. These, plus amaranth and desert broom, were important during late summer and fall and could replace saltcedar during this period when

saltcedar is considered important by beekeepers, if saltcedar were controlled (Table 58).

Table 58. Contribution of various plants to the annual pollen harvest of honeybees at 10 different apiaries within a 35-mile radius of Tucson (from O'Neal and Waller 1984).

Plant	% of annual pollen contribution
All Compositae (all year)	18.9
Mesquite (April-Oct.)	14.0
Creosotebush (March-Oct.)	10.4
<u>Heterotheca</u> (Aug.-Oct.)	9.6
Amaranth (July-Oct.)	6.0
Cottonwood (Feb.)	5.4
Saguaro cactus (May-June)	5.4
Alfilaria (Jan.-May)	5.3
Bladderpod (Feb.-April)	4.5
Desert broom (Sept.-Oct.)	3.2
Paperflower (anytime)	2.8

The presence of certain plants in the vicinity sometimes interferes with pollinating some crops. For example, bees, used to pollinate onion, often returned with pollen of saltcedar or arrowweed near Yuma or with pollen of mesquite or creosotebush in Pinal County (Waller and Buchmann, pers. commu.)

In Texas, the main crops pollinated by bees are cucumbers, cantaloupes, watermelons, citrus and other fruit trees, cotton, and sunflowers.

In Arizona, some beekeepers regard saltcedar as a very important plant and locate their apiaries in or near saltcedar thickets, whereas other beekeepers use it but little. Its main value is for colony maintenance in the fall, when other pollen and nectar sources may be scarce, especially in

dry years (Waller and Schmalzel 1976). Athel blooms from late July to early September and is especially attractive to bees. Saltcedar blooms from March to August. Both plants produce a strong-flavored honey with a yellow-green color. Honey from athel is suitable for colony maintenance but not for sale. Beekeepers in Arizona usually do not obtain a surplus from either plant, but those in New Mexico do obtain a small surplus from saltcedar, which is sold to the baking industry (Sauriol 1967, Waller and Schmalzel 1976; M.D. Levin, Honey Bee Res. Unit, USDA-ARS, Tucson, AZ, pers. comm.).

In 1988, a survey questionnaire was sent by G. D. Waller (Honey Bee Res. Unit, USDA-ARS, Tucson, AZ) to beekeepers in Arizona, New Mexico and Texas requesting their opinion about the 10 most important bee plants for both 1) honey production and 2) general colony maintenance. Twenty-five Arizona beekeepers who responded were from the following locations: Black Canyon City, Buckeye, Chandler, Coolidge, Flagstaff, Florence, Glendale, Goodyear, Holbrook, Palo Verde (CA), Parker, Phoenix (6), Tucson (4), and Yuma (2). Twenty responding beekeepers were each operating colony numbers from 100 to 1500 colonies; two had fewer than 100 and three had more than 1500. Thus, the survey included a cross section of part-time and commercial beekeepers over much of Arizona who operate approximately 30,000 colonies.

New Mexico has considerably fewer beekeepers than does Arizona. Waller received 11 responses from New Mexico beekeepers listing the following addresses: Belen, Bosque, Bosque Farms, Carlsbad, Deming, El Paso (TX), Gary (TX), Loving, Questa, Socorro, Winston, and one with no address listed. Of these, only 2 listed 10 honey plants and only one listed 10 maintenance plants. With one exception, these respondents kept 250 colonies or less. In fact, 10 of the 12 beekeepers who responded had a total of 752 colonies; one had several times this number and one did not say how many colonies he

operated. Major honey plants listed by New Mexico beekeepers were saltcedar, mesquite, alfalfa, sweet clover, cotton, and arrowleaf clover. The list for important maintenance plants given by New Mexico beekeepers had many of the same plants. The large commercial beekeeper rated saltcedar as the number one plant for both honey crop (40% of honey) and for colony maintenance (40% of pollen).

Hildebrandt and Ohmart (1982) reported that beekeeping in the Pecos River Valley was widespread and profitable in the early years of this century but today is much reduced because of a reduction in fruit orchards, and the use of pesticides that kill honeybees on agricultural crops. Today, most beekeepers are very mobile and move their colonies to exploit short-term resources, such as wildflowers and mesquite in the spring, fruit orchards at higher elevations, then cotton, which is the most important honey plant. They reported that saltcedar could be important before cotton flowering began; previous clearing projects have reduced this resource.

Responses from Texas beekeepers came from Houston, Moore, Navosota, Spring, and Vernon. Yaupon, Chinese tallow and cotton were rated best as a source of honey by these five Texas beekeepers. Each beekeeper chose as the number one maintenance plant a different species or 2 species as follows: agarito or ash (tie), blackberry, dandelion, elm, and saltcedar.

Of the 88 plants that Waller listed as possible candidates, the beekeepers selected in their "top 10" list 41 different plants for honey and 52 different plants for maintenance. Such varying opinions were not surprising considering the varied geographic and climatic conditions within Arizona. The "top 10" plants selected by the respondents were each assigned points that were in inverse proportion to rank; for example, 10 points for the #1 choice, 9 for #2, and 1 for #10. The numbers from each respondent were then

summed (Table 59). Some beekeepers reported saltcedar to be the most important plant for them for honey and pollen production. However, on the average, saltcedar ranked 7th among plants for honey production (one-fourth the value of the top plant, mesquite) and 4th for colony maintenance (two-thirds the value of the top plant, filaree). Saltcedar scored 56 of 963 points (5.8%) for honey production and 56 of 581 points (9.6%) for colony maintenance. Athel scored 14 points for honey production (11th) and 14 for maintenance (unranked). In 1983, Arizona and New Mexico together produced 4,094,000 pounds of honey. If 5.8% of the production were from saltcedar and honey sold for 40¢/lb, this could be worth \$94,981/yr. If it is worth an equal amount for colony maintenance, the total worth of saltcedar to the honeybee industry in Arizona and New Mexico together is only \$190,000/yr.

Brown (1989) conducted an economic analysis of the values contributed by saltcedar to the production of honey, beeswax and breeding queens in Arizona, New Mexico and Texas. Calculations were based on an average of 60 lb honey/colony/yr at \$0.60/lb, 1.25 lb beeswax at \$2.00/lb, and a number of queens for sale equal to the number of colonies in the state, at \$6.00 ea. He assumed a production of 17,700,000 lb honey, 368,750 lb beeswax, and 295,000 queens for the three states, valued at \$13,127,500. He then calculated the value of total production and the proportion contributed by saltcedar (Table 60).

Brown (1989) concluded that, since saltcedar at present is considerably underutilized by honeybees, sufficient saltcedar would remain after a 50% successful control program and that no economic losses would occur. However, he concluded that a 90% effective control program would produce a total annual loss in the three states of \$961,300 (7.3% of production), based on the present average production of 60 lb surplus honey per colony (Table 60).

Table 59. The top ten bee plants as selected by 25 Arizona beekeepers in a survey designed to determine those plants best suited for honey production and for colony maintenance (G. D. Waller, Honey Bee Res. Unit, USDA-ARS, Tucson, AZ, 1988, unpubl.).

Honey plants			Maintenance plants <sup>a/</sup>		
Rank	Name	Points	Rank	Name	Points
1	Mesquite ( <u>Prosopis</u> spp. mostly <u>velutina</u> )	227	1	Filaree ( <u>Erodium cicutarium</u> + <u>E. texanum</u> )	85
2	Catclaw ( <u>Acacia greggii</u> )	151	2	Mesquite ( <u>Prosopis</u> spp. mostly <u>velutina</u> )	66
3	Cotton ( <u>Gossypium</u> spp.)	104	3	Globe mallow ( <u>Sphaeralcea</u> spp.)	62
4	Citrus ( <u>Citrus</u> spp.)	97	4	Saltcedar ( <u>Tamarix chinensis</u> )	56
5	Alfalfa ( <u>Medicago sativa</u> )	83	5	Creosotebush ( <u>Larrea tridentata</u> )	50
6	Palo verde (mostly <u>Cercidium</u> spp.)	82	6	Cottonwood ( <u>Populus fremontii</u> )	47
7	Saltcedar ( <u>Tamarix chinensis</u> )	56	7	Fairyduster ( <u>Calliandra eriophylla</u> )	46
8	Fairyduster ( <u>Calliandra eriophylla</u> )	51	8	Palo verde (mostly <u>Cercidium</u> spp.)	45
9	Saguaro ( <u>Carnegiea gigantea</u> )	47	9	Desertbroom ( <u>Baccharis sarothroides</u> )	42
10	Wild buckwheat <sup>b/</sup> ( <u>Eriogonum</u> spp.)	33 <sup>b/</sup>	10	Catclaw ( <u>Acacia greggii</u> )	34
11	Athel ( <u>Tamarix aphylla</u> )	14	10	Arrowweed ( <u>Pluchea sericea</u> )	34
TOTAL		963			581

<sup>a/</sup> Athel also had a total of 14 points as a maintenance plant but did not rank in the top 10 species.

<sup>b/</sup> All buckwheats combined.

honey - SC = 5.8% of total points

maintenance SC = 9.6% "

Table 60. Production and value of honeybee products and amount contributed by Tamarix (saltcedar plus athel) (from Brown 1989).

	No. colonies	Annual production			Value (\$ million)	
		Honey (million lb)	Beeswax (lb)	No. queen	Total	From saltcedar <sup>a/</sup>
<u>Value of products:</u>						
Arizona	75,000	4.5	93,570	75,000	3.337	0.626
New Mexico	20,000	1.2	25,000	20,000	0.890	0.320
Texas	<u>200,000</u>	<u>12.0</u>	<u>250,000</u>	<u>200,000</u>	<u>8.900</u>	<u>0.534</u>
TOTAL	295.000	17.7	368,750	295,000	13.127	1.480
<u>Potential loss attributable to biocontrol:</u>						
50% effective biocontrol program						none
90% effective biocontrol program						0.961

<sup>a/</sup> Percent of total production  
 AZ = 40% of output from 75% of colonies = 18.75%  
 NM = 40% of output from 90% of colonies = 36.0%  
 TX = 40% of output from 15% of colonies = 6.0%

The values in Table 60 may somewhat overestimate actual losses. Brown (1989) assumed that saltcedar and athel together contributed 18.75% of total production in Arizona, 36% in New Mexico, and 6% in Texas. In the survey of Waller (1989), saltcedar ranked 7th for honey production and 4th for maintenance. These values have not been weighed for number of colonies of each resposdee, which could change the ranking substantially. Also, the linear relationship of assigning points is probably not realistic; the first 3 or 4 plants named by survey resposdees probably contributed more than half to the total, leaving saltcedar with considerably less than assumed in a linear relationship. Brown (1989) also did a second calculation based on a production of 200 lb honey/colony/yr, a level often achieved by the best producers. Losses caused by a 90% control program in this case could be \$2.27 million annually for Arizona, new Mexico and Texas combined.

The value of ~~saltcedar~~ to the honeybee industry is not very clear at this time. Some beekeepers use it to great advantage, obviously because: 1) it is there in great abundance, 2) it is very attractive to bees and provides an excellent pollen and nectar source, 3) it often grows near water that bees also need, 4) it often provides shade for the colonies, and 5) it is productive during a period in the fall when other pollen-nectar sources may be scarce. However, it produces a poor quality honey that is of little use as table honey but that is useful in the baking industry.

Saltcedar, in riparian areas, has primarily replaced cottonwood, willow, honey mesquite (or velvet mesquite in Arizona), screwbean mesquite, and seepwillow baccharis. All of these plants are also of great value for honeybees--cottonwood in February and willow in March (both for pollen), mesquite throughout the spring and summer (it produces large amounts of excellent quality honey), and seepwillow baccharis in the fall when other plants are scarce. If a reduction in saltcedar were to allow an increase in these native trees and shrubs, then its control might cause only minimal loss to beekeepers and could even be advantageous in some case since these plants produce a higher quality honeys.

A biological control program is very unlikely to reduce saltcedar density by more than 75-80%, which would leave a substantial amount that could be used by bees. The biological control approach under consideration can be directed to affect the deciduous, shrubby, weedy saltcedar (I. chinensis) but to have no effect on the evergreen, largely beneficial athel tree (I. aphylla). Athel, therefore, could be used by beekeepers as it is at present.

In the survey made by Scudday (see Sect. XV and Appendix III) of this report) none of the farmers and "tejido" managers in Sonora and northern

Sinaloa, mentioned honeybees or honey production when discussing the beneficial and harmful aspects of saltcedar and athel.

### XIII. VALUE OF SALT CEDAR FOR ORNAMENTALS

The numbers of each species of shade or ornamental trees in the yards of houses was measured by DeLoach et al. (in manuscript a, b) in Texas, New Mexico, Arizona, and parts of neighboring states. The towns were divided into from 3 to 10 more-or-less equal sections of residential areas and trees were counted at all houses in 5 continuous blocks on one side of the street in each section; trees were classed as small, medium and large. Values were assigned to the different species and size classes (Neely 1988) based on location, condition, the "intrinsic" value of the species as a landscape tree, and a value of \$25.00 per square inch of cross-sectional area of the trunk. Calculations were done separately for each Major Land Resource Area (MLRA) (SCS-USDA 1978). The value of one large tree varied from \$530 to \$2535 for the different species. The sample values were extrapolated, using total numbers of single-unit residences from the various reports of the 1980 census, to obtain total numbers of each tree species and the total dollar value of each species in each MLRA and in each state.

#### A. In Texas

In Texas, saltcedar was found in only 7 of the 12 MLRA's sampled in the state. DeLoach et al. (in manuscript a) counted a total of only 26 small, 26 medium and 67 large Tamarix trees in the yards of 5,556 houses in 77 towns. By extrapolation from this sample to all houses in these 7 MLRA's, they calculated that a total of 73,210 large-tree-equivalent trees were used in the entire area, valued at \$50.972 million (Table 61).

Unfortunately, they did not distinguish between saltcedar and athel in their survey. However, some estimate of the numbers and value of each can be obtained. Winter temperatures in the High Plains Trans Pecos, Rolling

Table 61. Number and value of Tamarix (saltcedar + athel) used as ornamental and shade trees in 7 of the 12 Major Land Resource Areas of Texas (fr DeLoach et al. in ms a).

MLRA	No. sampled		No. Tamarix trees in sample			% of total trees (LTE)		Total number of large trees (LTE) extrapolated for the area (X1000)		\$ Value Tamarix extrapolated for entire area (million)	
								Towns	Houses		S
Trans Pecos	9	610	6	11	20	2.80	1.41	12.83	2,842	451.0	8.933
High Plains	7	588	2	0	0	0.03	0.02	0.18	0,026	700.1	.122
Rolling Plains	12	930	3	1	0	0.07	0.04	.30		710.0	.210
Edwards Plateau	13	625	1	0	2	0.32	0.11	.63		859.6	.437
Rio Grande Plains	16	1,015	6	11	36	1.49	1.49	22.06	1,481	1,485.1	15.360
Blackland Prairie	13	1,175	4	3	2	0.12	0.12	7.70	0,126	6,657.8	5.360
Coastal Prairies	7	613	4	0	7	0.30	0.30	29.52	0,308	9,993.1	20.550
TOTAL OR MEAN	77	5,556	26	26	67	1.42	0.35	73.21 <sup>a/</sup>		20,856.7 <sup>a/</sup>	50.972 <sup>a/</sup>

<sup>a/</sup> Totals are from a "whole-state" analysis; these extrapolated values do not equal the sum of the MLRA's because of the stratified sampling design. 0.358 of 2

Plains, Edward Plateau, and Blackland Prairies are too cold for survival of athel, except possibly in the southern part of the Edwards Plateau (Del Rio) and the Blackland Prairies (San Antonio) and Trans Pecos (Presidio and El Paso).

Multiplying the extrapolated total number of trees and dollar value for each MLRA by the estimated proportion of athel and saltcedar (Table 62) gives a total of 40.63% saltcedar and 59.37% athel, and a total value of \$20.711 million for saltcedar and \$30.261 million for athel.

Many of the plants in the Coastal Plain MLRA are probably Tamarix gallica, which invaded this area in the mid-1800's. However, these are small trees, similar to saltcedar of the western areas, and probably are outvalued by the much larger athel trees which can survive this coastal climate.

Table 62. Calculation of the proportion and value of athel and saltcedar in Texas (from DeLoach et al. in ms a).

MLRA	% of trees		Total estimated value (millions)	
	Saltcedar	Athel	Saltcedar	Athel
Trans Pecos	90	10	\$ 8.040	\$ 0.893
High Plains	100	0	.122	0
Rolling Plains	100	0	.210	0
Edwards Plateau	80	20	.350	.087
Rio Grande Plains	10	90	1.536	13.824
Blackland Prairie	80	20	4.288	1.072
Coastal Prairies	30	70	<u>6.165</u>	<u>14.385</u>
TOTAL			\$20.711	\$30.261

A biological control program that differentiated between saltcedar and athel would, then, have the potential to damage only \$20.7 million worth of saltcedar used as shade or ornamentals in Texas.

#### B. In Arizona and Neighboring States

In the sample area of Arizona and parts of neighboring states, DeLoach et al. (in manuscript b) counted 10,655 trees (2,805 small, 4,846 medium, and 3,004 large) in the front and side yards of 1,851 houses (0.12% of the total houses present) in 36 towns and cities in 8 MLRA's. Of those, 21 towns were in Arizona, 5 in southeastern California, 2 in southern Nevada, 1 in southern Utah, and 6 in western New Mexico. Total number of houses, both in cities and towns and in rural areas, was 1,557,669 from the Census Report and our calculations of the total value of all shade and ornamental trees was \$5.713 billion, giving an average value of \$3,717 per house (Table 63).

The 12 most used species were mulberry, palms, elms, eucalyptus, poplars, Italian cypress, pines, arborvitae, oleander, tree of heaven, Russian olive, and ash (Table 64), which together accounted for 73.09% of all trees used

Table 63. Number and value of all trees per house in each MLRA (from DeLoach et al. in ms b).

MLRA	No. towns sampled	No. houses counted	Number trees per house				Value all trees per house
			S	M	L	LTE	
Sonoran Bsn & Rng-30	5	285	1.24	2.18	1.69	2.60	3,619
Imperial Valley-31	5	236	1.91	3.39	1.78	3.16	4,661
Col.&Green Riv Plat-35	2	65	1.23	1.69	1.60	2.30	2,848
NM/AZ Plat & Mesa-36	1	47	1.47	1.87	1.21	2.06	2,871
AZ/NM Mt.-39	4	158	1.58	2.71	2.33	3.41	4,687
Cen. AZ Bsn & Rng-40	5	348	1.84	2.92	1.48	2.74	4,147
SE AZ Bsn & Rng-41	8	448	1.54	2.45	1.30	2.26	3,334
S Desert Bsn, Pt, Mt-42	<u>6</u>	<u>264</u>	0.98	2.40	1.53	2.48	<u>3,149</u>
TOTAL or MEAN	36	1,851					3,717 <sup>a</sup>

<sup>a</sup>/ Sums of MLRA's do not add to total for entire area because of stratified sampling.

(DeLoach et al., manuscript b). They listed separately the species that are considered to be weedy in rangelands (Table 65). The most notable was Russian olive which ranked 11th among the most used shade tree species, with a value of \$234 million. Saltcedar was used only occasionally. They counted only 7 small, 20 medium and 13 large trees in the yards of 1,896 houses sampled, with a total value extrapolated to the entire sample area of \$13.425 million, or only 0.24% of the value of all trees. Athel was used only slightly more; they counted 4 small, 15 medium and 17 large, for a total value of \$15.876 million. Nearly all of the usage of saltcedar and athel was in four of the nine MLRA's: in MLRA-42, saltcedar constituted 0.71% of all trees and in MLRA-41, 0.66%, but no more than 0.19% in any other MLRA (Table 65).

The total value of saltcedar used in Arizona (plus parts of four neighboring states) and Texas was calculated to be ca. \$34 million.

Table 64. Twelve most used trees in Arizona and adjacent areas of neighboring states (from DeLoach et al. ms b).

MLRA	No. towns sampled	Large tree equivalents (LIE's) per house (% of all trees)											
		Mul.	Palm	Elm	Eucl	Popl	Cypr	Pine	Arbor Oldr	Hvn	Rus	Olv	Ash
Sonoran Bsn & Rng-30	5	19.73	4.86	5.51	3.07	6.34	14.39	2.21	7.44	5.49	5.05	6.38	1.43
Imperial Valley-31	5	8.96	25.81	4.01	7.85	0.23	3.09	2.45	2.75	11.63	0.91	3.23	4.60
Col.&Green Riv Plat-35	2	8.52	0	32.45	0	25.62	0	0.91	4.82	0	1.40	1.34	3.15
NM/AZ Plat & Mesa-36	1	0.65	0	62.19	0	12.78	0	1.59	0.79	0	2.04	7.58	0
AZ/NM Mt.-39	4	7.10	0.13	13.30	0	11.77	2.13	22.75	2.91	1.26	8.18	0.07	1.20
Cen. AZ Bsn & Rng-40	5	6.74	17.45	0.49	21.89	3.24	2.97	5.84	4.96	5.50	0.34	5.86	2.65
SE AZ Bsn & Rng-41	8	9.92	5.33	4.47	2.35	1.79	12.15	3.39	9.75	8.22	4.69	1.69	4.25
S Desert Bsn, Pl, Mt-42	6	14.31	0.23	8.38	0	12.21	1.40	7.87	8.18	1.32	4.47	1.78	3.51
Wasatch & Unita Mts.-47	1	0.89	0	10.91	0	15.90	0	0.44	3.19	0	2.14	0	21.18
TOTAL AREA MEAN		10.54	9.07	7.32	6.31	6.12	6.07	6.07	6.06	5.40	3.50	3.33	3.30

Table 65. Value of shade trees (and their beneficial close relatives) in Arizona and neighboring states that are also weedy trees of rangelands (from Deloach et al. ms b).

MLRA	\$ Value (X1000)									
	Tamarix		Mesquite		Juniper	Russian olive	Creo- sote	Desert broom	All trees	
	Salt- cedar	Athel	Velvet	Alba						
Sonoran Bsn & Rng-30	1,379	1,615	0	0	8,106	55,194	0	0	869,717	
Imperial Valley-31	0	2,784	1,789	1,543	0	6,866	929		226,852	
Col.&Green Riv Plat-35	110	0	0	42	0	931	0	0	62,373	
NM/AZ Plat & Mesa-36	108	0	0	0	685	4,350	0	0	58,116	
AZ/NM Mt.-39	0	0	2,715	2,480	4,959	157	0	631	237,513	
Cen. AZ Bsn & Rng-40	1,786	5,018	0	227	3,717	140,210	0	2,623	2,620,266	
SE AZ Bsn & Rng-41	3,845	4,330	17,461	26,972	3,212	9,235	0	11,635	582,298	
S Desert Bsn, Pt, Mt-42	6,197	2,579	688	4,273	32,313	17,012	0	0	878,109	
Wasatch & Unita Mts.-47	0	0	0	0	0	0	0	0	177,543	
TOTAL	13,425	15,876	22,653	35,537	52,992	233,955	929	14,889	5,652,757	
% OF TOTAL	0.24	0.28	0.40	0.63	0.94	4.14	0.02	0.26	100.00	

In his economic analysis, Brown (1989) used replacement cost obtained from local nurseries of \$85 for a small tree, \$250 for a medium, and \$475 for a large tree, with an additional mileage cost to replace trees in rural areas. He calculated the replacement value of the trees estimated in the samples of DeLoach et al. (in ms a,b) as \$11,351,660 in cities and \$2,604,950 in rural areas, for a total of \$13,956,610 in Texas, New Mexico, Arizona, and small areas of southern California, Nevada and Utah. He spread these costs over the 10 years of a biological control program after which no more loss was assumed since the replacement trees would be at least as valuable as the saltcedars. Using an 8% interest rate, he estimated \$698,000 in annual damages with 50% biocontrol and \$1,256,000 annually with 90% biocontrol.

#### XIV. WINDBREAKS, SOIL-STABILIZATION AND OTHER BENEFICIAL USES

Brown (1989) reported that saltcedar has been used as windbreaks in the Rio Grande Valley of Texas to protect citrus groves and sensitive vegetable crops. Irrigation canals, stock watering areas and pastures are protected by windbreaks to reduce erosion and lessen the buildup of sediment in waterways (Padgett 1952). In the Coachella Valley, CA, saltcedar has been planted in single rows along both sides of a railroad track for protection against blowing sand. This enabled trains to operate at higher speeds and has reduced the rate of wear on the tracks (Brooks and Dellberg 1969). *Athel* (*T. aphylla*) has been the most preferred species for windbreaks because of its rapid growth, drought tolerance, and evergreen characteristics and *T. gallica* has been used to a much lesser extent (Lyles et al. 1984); however, the deciduous *T. chinensis* is rarely used as a windbreak plant. *Athel* was introduced into Arizona in 1911 from Algiers and planted widely in the southwest; by 1948, nearly all new windbreak plantings were of *athel*. It was introduced into Australia from California for use as windbreaks before 1936 (Cuthbertson 1948). It has since become a major pest in some areas of Australia (Graham Griffin, CSIRO, Australia, pers. comm., 1990) and it is under consideration for biological control there.

The control of saltcedar may adversely affect riverbank stabilization since *T. chinensis* is the most common species in these areas. The extent of these impacts is unclear because replacement vegetation will partially offset the loss of the saltcedar. Also, the roots of the dead saltcedar will remain essentially in place for a few years while other vegetation is becoming established. Saltcedar sometimes has been planted around oil wells for soil stabilization and to reduce blowing sand.

On the Indian Reservations of the southwestern U.S., ~~it is~~ probably used occasionally for firewood, fenceposts, etc. A survey conducted by Charles Tiernan of the USDA-Forest Service in 1978 indicated little opposition to a biological control program by the Tribal Councils of several southwestern Indian Reservations, which indicated that it was little used.

Gary (1960) found that, on the Salt River, AZ, cattle grazed extensively on the sprouts of plants clipped to 6 in. high. As the plants grew taller, the cattle grazed only on the terminals and by autumn some plants were too tall for the cattle to reach. Sprout weight of grazed plants was 50-60% less than of ungrazed, clipped plants. He did not report on the nutritional value of this forage for cattle.

## XV. USAGE IN MEXICO

Scudday (Appendix III, this report) conducted interviews with 36 local farmers and "tejido" (cooperative farm) managers in Sonora and northern Sinaloa regarding their perception of the usefulness of saltcedar and athel. A similar but more extensive survey is presently being conducted across northern Mexico from Tamaulipas to Sonora by personnel of the Department of Renewable Natural Resources, Univ. Autonoma Agraria "Antonio Narro," Saltillo.

Scudday (Appendix III, this report) surmised that, historically, the planting of Tamarix chinensis as windbreaks in Mexico was encouraged by Mexican governmental agencies, which furnished young trees and/or rooted cuttings. The plant was favored because of its quick growth and drought tolerance. It was also a favorite ornamental species for planting around homes. Those trees are now very large and are commonly found in all urban areas.

Later, the planting of Tamarix aphylla was encouraged as windbreaks around fields and along irrigation canals. Because T. aphylla is not such an aggressive invader species as T. chinensis, the plant did not spread as rapidly into unwanted areas. Also, the wood was considered to be of much better quality than T. chinensis for most uses, especially for straight fence posts.

A third stage then occurred when T. chinensis began to escape cultivation and spread along riparian routes, just as it has done in the southwestern U.S. Where it has now persisted for the past 20 years or more, it has become a problem in agricultural areas. At present, government agencies seem to be discouraging the use of saltcedar. Several species of Eucalyptus and a saltcedar look-alike referred to as Casaurina appear to be the arid-adapted trees being encouraged for planting.

Scudday (Appendix III, this report) concluded that the great majority of the 36 respondents to his questionnaire perceived saltcedar as a pernicious invader and could see little use for it.

Large and mature I. chinensis were found only in the yards of homes, where they were prized as ornamentals and for shade, or bordering some fields where they were obviously planted as windbreaks. Probably every town and village had at least a few mature I. chinensis trees. In considering the nature of the two species of Tamarix, the respondents generally acknowledged that athel (I. aphylla) mostly stayed where it was planted, but saltcedar (I. chinensis) spread to areas where it was not wanted.

Farmers collectively complained of the invasion by saltcedar. One older man said there was no problem with it along the Rio Sonora until about 15 years ago. Apparently, the spread of the more weedy saltcedar has been relatively recent. Nearly all farmers agreed that even goats seldom eat it, but sometimes it did provide shade for the livestock.

Athel was usually considered to be much more useful than was saltcedar. In their study area, athel was being cut for fence posts, but the cutters said it made inferior posts and would soon rot. They also found that birds seemed to prefer it, possibly only because of its greater height. Two bee colonies were discovered near the tops of two athel trees. Although saltcedar is considered a suitable honey tree in the U.S., none of the persons interviewed in Mexico mentioned bees or honey when discussing the pros and cons of saltcedar.

The results of the questionnaire were as follows:

Question 1: "Is saltcedar present nearby?"

Answer: Yes-95%; do not know the plant-5%

This question was strongly biased because the question was always posed in an area where saltcedar occurred. The two respondents who did not recognize saltcedar were in Sinaloa where saltcedar is thought by some to be a kind of pine.

Question 2: "Is saltcedar a recent or a long-time plant in this area?"

Answer: Long-time-55%; short-time-35%; no answer-10%

Those who volunteered a time-frame mostly cited 6 to 15 years for a long time, and 2 or 3 years for a short time. A 60-year-old field foreman at Ejida La Florida indicated saltcedar had been around for 40 years.

Question 3: "Is saltcedar a useful plant (and for what) or is it of little or no use?"

Answer: Some use-80%; very useful-6%; no reply-14%

3a. How was it used? This is presented in number of respondents rather than as a percentage because some individuals supplied more than one use. The uses stated broke down as follows:

For shade value	34	For posts	6
For wood	5	As an ornamental	3
As a windbreak	6	For stakes	1
For furniture	1		

3b. What harm does it cause? Responses were:

Kills other trees.	Causes salty soil.
It's like a weed.	It ruins farming.
Doesn't let grass grow under it.	
Where it drops its leaves, nothing grows.	
It invades fields and is difficult to control	

Question 4: "Have you noted birds or other wildlife using saltcedar?"

Answer: Some usage-52%; no usage-30%; no answer-18%

a. How is it used? Most of the positive answers reflected avian use:

Grackles roost there	7
Birds roosting (other kinds)	3
Birds nest	8
Jackrabbits	1

b. Do domestic animals use saltcedar, and in what way?

Answer: Some use-61%; no use-39%

Ways that livestock utilized saltcedar were listed as:

Use it for shade	7
Pigeons and chickens use it for shade	2
Horses, cows and goats eat it	8
Only goats eat it	2

Question 5: "If saltcedar disappeared--from--the--area,--would--you miss it?

Answer: Would miss it-34%; would not miss it-66%

This question received the most responses. Several persons commented on beneficial usage for shade, ornamentals, and wildlife cover but generally thought that other trees were better. Several commented that saltcedar increased soil salinity, clogged drainage ditches, blocked the course of the Rio Sonora and was a pest in agricultural areas (pastures, crops, vinyards) (see Appendix III).

Scudday (Appendix III, this report) also interviewed a farmer near Hermosillo who had a degree in agronomy and was growing safflower on the floodplain of the A. Rodriquez Reservoir on the Rio Sonora. Young plants of saltcedar grew to the edge of his field. He stated that in February 1988 the area was under water and no saltcedar was present. At the time of the interview (May 1988), the area was covered with young, spindly saltcedar plants, many of which were flowering. Through this farmer, they contacted the director and a range ecologist at the School of Agriculture and Ranching, University of Sonora, who were very much interested in controlling saltcedar.

## XVI. NATURAL ENEMIES OF SALT CEDAR

### A. In North America

Since saltcedar is an introduced plant in North America and no other species of the genus Tamarix or of the family Tamaricaceae occur here, any native natural enemies would necessarily be polyphagous species. Hefley (1937) mentioned a few insects that damaged saltcedar in Oklahoma. Hopkins and Carruth (1954) found 56 species of insects on saltcedar in Arizona; of these, 21 species fed on the plant but only 3 species caused damage. These were the false chinch bug, Nysius ericae, that was commonly found but damaged only one tree at one location, the Apache cicada, Diceroprocta apache, and the alien leafhopper, Opsius stactogalus, that was host specific on Tamarix and was present in all areas in large numbers.

Liesner (1971) and Watts et al. (1977) studied the insects of saltcedar in New Mexico; of 159 species of insects and one species of mite collected, damage was limited to isolated instances of one or a few trees except for the two alien insects, O. stactogalus, and the scale insect, Chionaspis etrusca. Opsius stactogalus was regularly found in moderate to large numbers. Field populations had a suppressing effect on saltcedar growth and caged 1-year-old plants where leafhoppers were excluded produced 74% more growth than adjacent similar uncaged plants that were exposed to leafhoppers. Leafhoppers introduced weekly onto caged plants reduced plant growth even more. Chionaspis etrusca was found mostly in southern New Mexico but large populations were uncommon (Watts et al. 1977).

Glinski and Ohmart (1984) found very high populations of the native Apache cicada in saltcedar stands in southeastern Arizona. The nymphs probably feed on the roots of saltcedar and on those of its natural hosts

(cottonwood, willow, baccharis, mesquite, and other plants) for 2 to 3 years; the full-grown nymphs then emerge from the soil, attach themselves to a plant stem, and the adult emerges. The cast exuviae were found from July 8 to August 19 but large numbers were present only for a brief period of 2 weeks in mid-July when the population reached 16/m<sup>2</sup>. The adults caused some damage by ovipositing in the stems and the nymphs undoubtedly caused some damage to the roots. The Apache cicada is a pest of asparagus and date palms.

Watts et al. (1977) found no plant pathogens (other than saprophytes) that attacked saltcedar in New Mexico. However, Brown (1953) reported isolating a bacterium from dying plants in Arizona that killed healthy plants in the greenhouse when sprayed on them.

Stevens (1985) compared the community dynamics of the herbivorous insects on saltcedar and coyote willow (*Salix exigua*) in Grand Canyon, AZ, from 1980-83. In saltcedar, he found only a few species that were highly unevenly distributed, and of a large biomass. Coyote willow had a much more diverse herbivore community, but the numbers were only slightly less variable than in saltcedar, and biomass was much less, as follows:

	Saltcedar	Willow	
Number individuals (720/50 sample)	$\bar{x} = 322.2 \pm 510.1$	$\bar{x} = 394.7 \pm 696.4$	(#S)
Number species per 50 samp sample	$3.61 \pm 1.64$	$12.0 \pm 4.33$	( $p > 0.001$ )
Biomass (mg/g leaf)	$3.59 \pm 4.18$	$0.22 \pm 0.18$	( $p > 0.001$ )

Stevens 1985  
 ← pg 61

why only 5 S  
 of saltcedar?

In saltcedar, the number of individual insects varied greatly between plots (from 71 to 655, total of 4 years) and between years within each plot (89-533, 44-1308, 23-144). Numbers in willow were somewhat less variable. Number of species collected per plot varied from 2.0 to 4.5 in saltcedar and from 7.0 to 17.0 in willow.

The herbivores of saltcedar were almost exclusively dominated by the introduced cicadellid, Opsius stactogalus, with minor occurrence of the mirid Parthenicus sp. nr. ruber. A scale insect, probably the introduced Chionaspis etrusca, was sometimes abundant in late summer. Nymphs of the cicada, Diceroprocta apache, were commonly associated with saltcedar roots at densities exceeding 6 nymphs/m<sup>3</sup>. Conspicuous insect damage was not found in the wood of saltcedar (Stevens 1985).

Stevens (1985) listed 145 species of insects collected from saltcedar in the United States (112 of them identified to species or near) by Bibby (1942), Glinski and Ohmart (1984), Hopkins and Carruth (1954), Hefley (1937), Liesner (1971), Watts et al. (1977) and his own study.

#### B. In Other Areas of the World

The insects attacking Tamarix in its native range have been much surveyed except in China. Lozovoi (1961) listed 52 insect species from Georgia, USSR; Zocchi (1971) listed 92 species from Italy, including 42 monophagous ones; and Pemberton and Hoover (1980) listed 26 species from Turkey.

1. In Israel, Turkey, Iran and India. Gerling and Kugler (1973) studied the insects and mites attacking various species of Tamarix in Israel (including the Sinai Peninsula) during 1970-1973; this included one collecting trip through Turkey, Iran and western India during 1972. At first, they collected bi-weekly from 29 sites but later reduced that to three main sites along the Dead Sea, with supplemental collections in the coastal area and occasional trips into the Sinai. Altogether, they sampled 119 sites in Israel. They made biological observations of the more important species on potted plants in the laboratory. A more detailed study of the gall insects was published separately (Gerling et al. 1976).

Gerling and Kugler (1973) listed 220 species of phytophagous arthropods (5 mites, 81 Coleoptera, 10 Diptera, 47 Hemiptera, 47 Homoptera, 28 Lepidoptera, and 2 Thysonoptera) and 48 species of Hymenoptera that parasitized them. They conducted more detailed observations on 24 species that appeared to be the more important herbivores (Table 66). The 25 more important species can be grouped into four classes as potential biocontrol agents (Table 67). In the first class are two foliage-feeding larvae of moths, Agdistis tamaricis and Ornativelva spp., and two gall-forming midges, Psectrosema sp. 2 and Dasineura tamaricina. These all cause heavy damage, are moderately abundant and do not attack I. aphylla.

In the second class are species that also are highly or moderately abundant and cause heavy damage, but their ability to attack I. aphylla is not clear at present. These include a moth and a leaf-beetle foliage feeders, two scale insects that attack branches, and a psyllid that produces galls on buds and flowers (Table 67).

In the third class are 6 insects and 2 mites that were observed to cause little damage to the plant, although they did not attack I. aphylla. In the fourth class are 6 insects and 2 mites known to attack I. aphylla; all but the mites cause heavy damage (Table 67).

Gerling and Kugler (1973) found three factors of importance in the selection of effective and safe biocontrol agents for saltcedar. First, only a few of the mites and insects were able to attack, or at least to cause much damage, to I. aphylla compared with the number on other Tamarix species. Second, many of the insect species that they observed more carefully were heavily attacked by parasites and/or predators. Third, several of the more damaging and widespread species that attacked deciduous saltcedar also attacked I. aphylla to some degree. They gave no information on the other

able 66. Insects and mites that attack Tamarix spp. in Israel, Turkey, Iran, and western India (from Gerling and Kugler 1973).

Herbivore name (family)	Damage		Abund. a/	Dist. b/	Host range	
	Type	Amount			Tamarix spp.	I. aphylla
-----Gall formers-----						
ACARINA						
<u>Idulcia tamaricum</u> (Tenuipalpidae)	cone-bark	little	C, La	Is, In	nilotica	No
<u>Idulcia</u> sp. (Tenuipalpidae)	wound-bark	little	A	Is, In	nilotica	+
<u>Eriophyes</u> n. sp. (Eriophyidae)	kernel-flower, terminal	little	VA	In, Ir	ericoides hispida	No
<u>Eriophyes tlaiae</u>	blister-green stems		C	Is, S, T Is, S, NAfr,	nilotica aphylla only	+
DIPTERA						
<u>Dasyneura tamaricina</u> (Cecidomyiidae)	buds	kill buds(?)	A	Is, Egypt	tetragnyna nilotica	No
<u>Psectrosema</u> spp. (Cecidomyiidae)	cigar-green stems	stunt terminal	C	Is, S, NAfr	? dioica?	No
<u>Misopatha tamarici</u> (Cecidomyiidae)	sphere-stem	little	LVA	In		
HOMOPTERA						
<u>Prastina</u> (?) <u>tamaricina</u> (psyllid)	bud, lf, flower	stunt	C	Is, S, USSR, NAfr	nilotica africana	No
COLEOPTERA						
<u>Diocleonus clathratus</u> (weevil)	strobilus	slight?	LC	Is, S, Egypt	nilotica, T. sp.	No
<u>Corimallia</u> 13 spp. (weevil)	fruit, seed	greatly reduce seed	VA	Is, S, Ir, T, In	all	+
LEPIDOPTERA						
<u>Amblypalpis olivierella</u> (gelechiid)	spindle, yng stem	little	LVA	Is, S, In, Ir	nilotica x <u>A. fulvipes</u>	No
<u>Parapodia sinaica</u> (gelechiid)	spindle, yng stem	little	C	Is, S, In, Ir	Jordanis	usually

to No. 10, Gerling and Kugler, 1984 for

does not attack T. aphylla

able 66. contd. 1

Herbivore name (family)	Damage		Type	Abund. <u>a</u> /	Dist. <u>b</u> /	Host range	
	Amount					<u>Tamarix</u> spp.	<u>I. aphyll</u>
-----Foliage feeders-----							
COLEOPTERA							
<u>Cryptoccephalus fulgurans</u> (chrysomelid)			yng stem	A	Is, S, In, Ir	?	?
<u>Oniatius</u> spp. (weevil)	much		yng stem		Is, S, In, T, Ir Is, In, Ir, T		
LEPIDOPTERA							
<u>Arnativalva heluanensis</u> (gelechiid)		also borer			Is, S, T	smyrensis	
<u>Plutelliformis</u> (gelechiid)		also borers			Is, T	smyrensis	
<u>Epidoqma tamaricalis</u> (pyralid)		build webs			Is, In	nilotica	
<u>Emiothisa aestimaria</u> (geometrid)	much				Is, In, Ir, T		+(lab on)
<u>Gdistis tamaricis</u> (pterophorid)					Is, T		
<u>A. arabica</u> (pterophorid)							
-----Sap suckers-----							
HOMOPTERA							
<u>Aiacoccus minor</u> (pseudococcid)	much on nilotica little on aphylla	branches, flowers		L-VA	Is, S, Ir, T	nilotica	+
<u>Arbutina palaestina</u> (pseudococcid)				A	Is, S, Ir, T		
<u>Xyrrhachis versicolor</u> (spittlebug)	kills branches, entire plant	branches			Is, S, Ir, T		
-----Borers-----							
<u>Iteropsis squamosa</u> (buprestid)	much	stems, trunk			Is, S, Afr	all	+

✓ A-abundant, VA--very abundant, C-common, L-locally.

✓ Is-Israel, S-Sinai, T-Turkey, Ir-Iran, In-India, Afr-Africa.

Table 67. Suitability of insects and mites from Israel, Turkey, Iran and western India as biocontrol agents for saltcedar in North America (from Gerling and Kugler 1973, their Table 7).

Species (family)	Type damage <sup>a</sup> /	Abundance <sup>b</sup> /	Host range <sup>c</sup> /	Damage <sup>b</sup> /
<u>1st Class: Do not attack <i>I. aphylla</i>, cause heavy damage, and are highly or moderately abundant</u>				
<i>Agdistis tamaricis</i> (pterophid)	lf	M	rest	H
<i>Ornativalva</i> sp. (gelechiid)	lf	M	rest	H
<i>Psectrosema</i> sp. 2 (cecidomyiid)	st-g	LM	rest	H
<i>Dasineura tamaricina</i> (cecidomyiid)	sd, fl-g	M?	rest	H
<u>2nd Class: Attack on <i>I. aphylla</i> not certain, cause heavy damage, and highly or moderately abundant</u>				
<i>Lepidogma tamaricalis</i> (pyralid)	lf	LM	? rest	H
<i>Cryptocephalus fulgurans</i> (chrysom)	lf	LM	? rest	H
<i>Trabutina palacestina</i> (pseudococc)	st-sk	LM	? rest	H?
<i>Naiacoccus minor</i> (pseudococcid)	st-sk	LH	? rest	H?
<i>Crastina tamaricina</i> (psyllid)	t-g	LH	? rest	H-S
<u>3rd Class: Do not attack <i>I. aphylla</i>, abundance variable, cause slight damage</u>				
<i>Amblypalpis olivierella</i> (gelechiid)	st-g	LH-M	rest	S
<i>Parapodia sinaica</i> (gelechiid)	st-g	LM	rest	S
<i>Psiloptera rugosa</i> (buprestid)	br	LR	rest	?
<i>Buprestis hilaris</i> (buprestid)	br	LR	rest	?
<i>Obdulia tamaricum</i> (mite)	st-g	LH	rest	S
<i>Eriophyes</i> n. sp. (mite)	t, fl-g	H	rest	S
<i>Liocleonus clathratus</i> (weevil)	t-g	LR	? rest	S
<i>Psectrosema</i> sp. 1 (cecidomyiid)	st-g	H	rest	S
<u>4th Class: Attack <i>I. aphylla</i>, abundance and damage variable</u>				
<i>Semiothisa aestimaria</i> (geometrid)	lf	LH	all	H
<i>Sterapsis squamosa</i> (buprestid)	br	LH	all	H
<i>Coniatus</i> spp. (weevil)	st	M	all	H
<i>Corimallia</i> spp. (weevil)	fr-g	LH	all	H?
<i>Opsius</i> spp. (cicadellid)	st-sk	H	all	H
<i>Oxyrrachis versicolor</i> (spittlebug)	st-sk	H	all	H
<i>Tenuipalpid</i> sp. (mite)		LM	all	S
<i>Eriophyes tlaiae</i> (mite)		H	athel	S

<sup>a</sup>/ st=stem, sd=seed, fl=flower, fr=fruit, lf=leaf, g=gall, br=borer  
sk=sucking, t=terminal.

<sup>b</sup>/ H=high, M=moderate, R=rare, L=locally, S=slight.

<sup>c</sup>/ rest=all *Tamarix* species except *I. aphylla*.

196 species (those remaining from the 24 species observed more carefully) so no conclusion can be drawn regarding their potential. They do mention a few of these such as the leafhopper Opsius and the buprestid borers Psiloptera and Buprestis that could be good control agents.

Several of these insects (including these in Class 3) might be more abundant, and appear to be better biocontrol agents if their parasites were removed, which would be the case if they were introduced into the U.S. The possibility of attack on I. aphylla, and the degree of that attack, should be determined for several species, especially those in Class 2. Some of these probably attack I. aphylla not at all or only to a minor degree, which could be acceptable for use as biocontrol agents. Some of the more host specific and damaging insects attack flowers. These should not be considered as candidates for introduction at this time.

Compiling a single list of "best" candidate biocontrol agents from the two reports (Gerling and Kugler 1973, Habib and Hassan 1982) is somewhat difficult. Many of the insects occur in one area but not the other. Also, many species are not identified with certainty and in some cases reports of host range for the same insect differ. Habib and Hassan (1982) give information on all species collected but give little evaluation of damage potential of the insects. Gerling and Kugler (1973) evaluate damage and give other information on the 24 more important species but give nothing on the other 196 species. Neither research group tested the ramosissima/chinensis taxon that is the major pest in North America to determine if the more promising mites or insects would attack it. If damage to I. aphylla were not considered detrimental, then many more very effective species could be considered for biological control.

In a detailed study of the galls of Tamarix in Israel, Gerling et al. (1976) found 13 species of insects and mites that produced 10 distinctive types of galls, plus two other types of galls caused by unknown organisms. Six species of insects and 4 species of mites produced galls on I. jordanis, I. nilotica, I. tetragyna and a few other species but not on I. aphylla (Table 68). The gall-forming midges Dasyneura tamaricina and Psectrosema spp., the psyllid Crastina linnovuori and the weevil Liocleonus clathratus did not attack athel and were capable of severely damaging the trees in heavy attacks. Other gall formers were not observed to damage the plant.

2. In Pakistan. Habib and Hasan (1982) found 185 insect and 5 mite species of that feed on Tamarix in Pakistan; 124 of these were stenophagous and nearly half were oligophagous. They conducted more detailed investigations on 28 species that were more abundant and caused substantial damage in the field (marked with an asterisk in Table 69). Of these, 26 species seemed to be host specific to the genus Tamarix and they considered these to be possible biological control candidates. However, only 7 species of gall formers (6 Psectrosema and Amblypalpis olivierella) and 3 species of Ornativulva defoliators among these 26 species appeared not to feed on athel (I. aphylla). Their complete list included numerous other species that were less abundant. These were 24 species of gall formers, 3 flower feeders, 35 defoliators, 4 borers, and 22 sap suckers. Those that did not feed on I. aphylla were 19 species of gall formers, no flower feeders, 14 defoliators, 4 borers, and 8 sap suckers (Table 69).

Of the 12 species of defoliators that Habib and Hasan (1982) considered to be the best candidates (\* in Table 69), three species, Chelaris sp., Ornativulva n. sp. and Agdistis arabica, were not found on athel in their field collections. These all had short generation periods and thus

Table 68. The galls of Tamarix (not found on I. aphylla), their causative agents, distribution in Israel and the Sinai and their characteristics (from Gerling et al. 1976).

Causative agent	Type of gall	Nature of gall	Areas of occurrence	Host species	Type of damage <sup>a</sup>	Size of gall (mm)
Acarina, Tenuipalpidae <u>Obdulia tamaricis</u>	cone	conical postules on trunk	Rift Valley & Sinai	<u>nilotica</u>	1	2-3
Acarina, Eriophyidae <u>Eriophyes strobilobius</u> <u>E. sychytroides</u> <u>Eriophyes</u> sp.	kernel	small clumps on terminal parts of branches	everywhere	<u>ericoides</u> <u>hispida</u> <u>nilotica</u>	1	1-3
Diptera, Cecidomyiidae <u>Dasyneura tamaricina</u>	bud	buds develop scale-like covering & die	Negev & Rift Valley	<u>tetragyna</u> <u>nilotica</u>	1+3	7-10
<u>Psectrosemma</u> spp.	cigar	small thickenings on young branches	Negev, Rift Valley & Sinai	not given	1+2+3	4-8
Psylloidea, Aphalaridae <u>Crastina linnavuori</u>	strobilus	terminal leaves elongate, branch strobilus-like	Rift Valley & Sinai	<u>nilotica</u> <u>africana</u>	1+3	7-10
	flower	flower buds don't open, red then dry	Rift Valley, & Sinai	<u>nilotica</u>	1+4	1-2
Coleoptera, Curculionidae <u>Illoleonus clathratus</u>	balanus	swellings on root & trunk	lower Rift Valley, Sinai	<u>nilotica</u> <u>I. sp.</u>	1+2	2-4 cm. (15 cm+)

Table 68. contd. 1

Causative agent	Type of gall	Nature of gall	Areas of occurrence	Host species	Type of damage <sup>a/</sup>	Size of gall (mm)
Lepidoptera, Gelechiidae <u>Amblypalpis olivierella</u>	<u>Amblypalpis</u> spindle gall	spindle shaped thickenings on woody branches	everywhere	all except <u>aphylla</u>	1+2	2-3 cm.
Lepidoptera, Gelechiidae <u>Parapodia sinaica</u>	<u>Parapodia</u> spindle gall	usually irregular thickenings on woody branches	Rift Valley & Sinai	not given	1+2	8-12

<sup>a/</sup> 1-Breeding through seed production. 2-Portal of entry for pests and diseases; 3-0ie-back of branches;

Table 69. Insect herbivores that attack various species of Tamarix in Pakistan (partial list from Habib and Hasan 1982).

Insect name and family	Type damage <sup>a</sup> / collected <sup>b</sup>	Distrib. (No. loc. collected)	Stage collect.	No. spp. Tamarix attacked	Host range		
					Other genera attacked	Attacks I. aphylla	No other host known <sup>d</sup>
-----Gall Formers-----							
ACARINA - Eriophyidae							
<u>riophyes dioicae</u>	LB	3	I, A	1	--	No	
<u>. tlaiae</u>	lw	MA	I, A	1	--	+	
<u>riophyes</u> sp. 1	lw	1	I, A	1	--	No	
<u>riophyes</u> sp. 2	YB	1	I, A	1	--	No	
COLEOPTERA - Curculionidae							
<u>iocleonus clathratus</u>	St, R	3	P, A	2	--	+	
<u>anophyes minutissimus</u>	Sd	5	L, A	3+	--	No	X
<u>. notatipennis</u>	?	2	L, P, A	2	--	No	
<u>. setulosus</u>	Fr	MA	L, P, A	4	--	+	
<u>anophyes</u> sp. 1	Fr, Sd	1	L, P	1	--	No	
<u>anophyes</u> sp. 2	Fr, Sd	2	L, P	1	--	No	
<u>anophyes</u> sp. 3	St	3	L, P, A	2	--	No	
<u>urculionid</u> sp. "A"	St	2	L	1	--	No	
DIPTERA - Cecidomyiidae							
<u>Psectrosema maniae</u>	WSt	6	L, P	1	--	No	X
<u>Psectrosema indicum</u>	WSt	7	L, P	1	--	No	X
<u>Psectrosema reticulatum</u>	WSt	3	L, P	3	--	No	X
<u>Psectrosema unicornise</u>	YSt	2	L, P	1	--	No	X
<u>Psectrosema parvum</u>	YSt	6	L, P	2	--	No	X
<u>Psectrosema</u> sp. B	Fl	1	L, P	1	--	No	X

ble 69. contd. 1

sect name and family	Type damage <sub>a</sub> /	Distrib. (No. loc. collected) <sub>b</sub> /	Stage collect. <sub>c</sub> /	Host range			
				No. spp. Tamarix attacked	Other genera attacked	Attacks I. <u>aphylla</u>	No other host known <sub>d</sub> /
<hr/>							
LEPIDOPTERA - Gelechiidae							
<u>mblypalpis olvierella</u>	Tw	8	L, P	4	--	No	X
<u>atetris (?) sp.</u>	Tw	2	L, P	2	--	No	
<u>istotelia ingravata</u>	Tw, also borer	2	L, P	1	--	No	X
<u>ropodia sinaica</u>	Tw	7	L, P	5	--	+	
<u>leiodes sp.</u>	Tw	4	L, P	4	--	No	
<u>leiodes sp.</u>	Tw	6	L, P, A	3	--	+	
<hr/>							
-----Flower Feeders-----							
DIPTERA - Cecidomyiidae							
<u>isineura sp.</u>		5	L, P	4	--	+	
LEPIDOPTERA - Noctuidae							
<u>haracoma nilotica</u>		MA	L, P	7	--	+	
LEPIDOPTERA - Pyralidae							
<u>terographis sp.</u>		4	L	2	--	+	
<u>abilleela (?)</u>							
<hr/>							
-----Defoliators-----							
COLEOPTERA - Chrysomelidae							
<u>ryptocephalus analis</u>		1	A	1	--	+	X
<u>faustulus</u>		9	E, L, P, A	3	--	+	X
<u>undulatus</u>		MA	E, L, P, A	7	--	+	X
<u>orhabda elongata</u>		3	L, A	2	--	+	X
<u>aragdina unipuncta</u>		1	A	1	--	No	X
<u>tylosomus tamaricis</u>		1	A	1	--	+	X

Subject name and family	Type damage <sub>a</sub> /	Distrib. (No. loc. collected) <sub>b</sub> /	Stage collect. <sub>c</sub> /	No. spp. Tamarix attacked	Host range		
					Other genera attacked	Attacks I. aphylla	No other host known <sub>d</sub> /
COLEOPTERA - Curculionidae							
<u>Diapars aegyptiacus</u>		1	A	1	--	No	
<u>indicus</u>		15	E, L, P, A	4	--	No	X
<u>canorhinus rufirostris</u>		8	A	5	--	+	X
<u>litotrichelus juvenis</u>		1	A	1	--	+	X
LEPIDOPTERA - Cosmopterygidae							
<u>calenia sp. nr. vanella</u>	also Tw	3	L	1	--	No	
LEPIDOPTERA - Gelechiidae							
<u>istotelia sp.</u>		1	L	1	--	+	
<u>helaris sp.</u>		3	L, P	1	stenop?	No	
<u>rnativava erubescens</u>		1	L	1	--	+	X
<u>heluanensis</u>	MA	MA	L	9	Frankenia	+	
<u>indica</u>	MA	MA	L, P	3	--	+	X
<u>macrosignella</u>	1	MA	L	2+	--	+	
<u>plutelliiformis</u>	MA	MA	L, P	6	Rhus?	+	
<u>rufipuncta</u>	1	1	L	1	--	No	X
<u>serratisignella</u>	1	1	L	1	--	+	X
<u>sp. nr. serratisignella</u>	3	3	L	1	--	No	
<u>sp. nr. tamariciella</u>	3	3	L	3	--	No	
<u>rnativava n. sp.</u>	3	3	L	1	--	No	
<u>rnativava sp.</u>	3	3	L	2	--	No	
LEPIDOPTERA - Geometridae							
<u>pithecia utlimaria</u>	8	MA	L, P	5	--	+	X
<u>emiothisa streniataria</u>	MA	MA	L, A	7+	Acacia (?)	+	

ble 69. contd. 3

sect name and family	Type damagea/ b/	Distrib. (No. loc. collected)	Stage collect.c/	No. spp. Tamarix attacked	Host range		
					Other genera attacked	Attacks I. aphylla	No other host knownd/
LEPIDOPTERA - Noctuidae							
<u>ytie devia</u>		1	L	1	--	No	X
<u>illunaris</u>		3	L	2	--	No	X
<u>. syriaca</u>		12	L	5	--	+	X
<u>ypoglaucitis benenotata</u>		MA	L,P	7	Cassia, Dalbergia	+	
<u>rallellia rogenhoferi</u>		2	L	1	--	+	X
LEPIDOPTERA - Pterophoridae							
<u>gdistis arabica</u>		6	L,P	2	--	No	
<u>. tamaricis</u>		MA	L,P,A	5	Myricaria	+	
<u>distis sp.</u>		3	L	2	-	No	
LEPIDOPTERA - Pyralidae							
<u>epidogma obatralis</u>		MA	L,P,A	10	--	+	X
-----Borers-----							
COLEOPTERA - Apionidae							
<u>ion tamaricis</u>		MA	L,P,A	4	--	No	X
LEPIDOPTERA - Cosmopterygidae							
<u>calenia pachnodes</u>	Gst	2	L	1	--	No	X
<u>sp. nr. pachnodes/vanella</u>	Gst	3	L	2	--	No	
LEPIDOPTERA - Gelechiidae							
<u>istotelia ingravata</u>	Yst, also galls	3	L,P	3	--	No	X

le 69. contd. 4

Insect name and family	Type damage <sup>a</sup> / collected <sup>b</sup>	Distrib. (No. loc. collected)	Stage collect.	No. spp. Tamarix attacked	Host range		
					Other genera attacked	Attacks I. <u>aphylla</u>	No other host known <sup>d</sup> / 
-----Sap Suckers-----							
HEMIPTERA - Lygaeidae <u>theneis balcanica</u>		9	N, A	5	--	+	X
HEMIPTERA - Membracidae <u>tinotus brevicornis</u>		9	E, N, A	1	<u>Winthania</u>	+	
<u>invarius</u>		2	E, N, A	1		No	X
<u>inotus</u> sp.		3	N, A	2		No	
HEMIPTERA - Miridae <u>chenocrepis alboscuteallata</u>		1	A	2	--	+	X
<u>ponia elegans</u>		2	A	1	--	+	X
<u>ponia</u> sp.		5	A	1	--	No	
HEMIPTERA - Pentatomidae <u>chysmus rubripennis</u>		6	N, A	2		+	X
HOMOPTERA - Aphalaridae <u>lposcencia aliena</u>		2	N, A	1	--	No	X
<u>elegans</u>		1	N, A	1	--	+	X
<u>astina</u> (?) <u>tamaricina</u>		2	N	2		No	
HOMOPTERA - Cercopidae <u>idama producta</u>		1	A	1	--	No	X

able 69. contd. 5

nsect name and family	Type damaged/	Distrib. (No. loc. collected) <sup>b/</sup>	Stage collect. <sup>c/</sup>	Host range			No other host known <sup>d/</sup>
				No. spp. Tamarix attacked	Other genera attacked	Attacks I. aphylla	
HOMOPTERA - Cicadellidae <u>psius</u> sp. a,b,c <u>amaricella ribauti</u>		11 3	N,A E,N,A	3 3	-- --	+ +	X(?) X
HOMOPTERA - Diaspididae <u>discodiaspis</u> sp. nr. <u>tamaricicola</u> <u>hionaspis engeddensis</u> <u>ryptoparlatoreopsis halli</u>		8 2 9	N,A N,A N,A	4 2 5	-- -- --	+ + +	X X X
HOMOPTERA - Eriococcidae <u>eoacanthococcus tamaricicola</u>		2	N,A	1	--	+	X
HOMOPTERA - Pseudococcidae <u>urycoccus</u> sp. nov. A <u>urycoccus</u> sp. nov. B <u>aiacoccus serpentinus</u>	UB UB	1 2 9	N,A N,A N,A	1 1 4	-- -- --	No + +	  X
HOMOPTERA - Psyllidae identified sp.		3	N	2	stenoph?	No	

✓ Fl-flower; Fr-fruit; GSt-green stems; LB-leaf bud; R-root; Sd-seeds; St-stem; Tw-twigs; UB-under bark; WSt-Woody stems; YB-young buds; YSt-young stems

✓ MA-collected throughout most of the area.

✓ E-egg; L-larva; P-pupa; I-immature; N-nymph; A-adult.

✓ X-no other host known.

✓ Information from Harris (1983) and Habbib (1983).  
✓ Series on which preliminary testing was performed in the laboratory.

moderately high reproductive rates. Chelaria sp. preferred tender foliage and was more abundant in riverine areas; they collected it from I. dioica at Jhelum, Wazirabad and Lahore. It has no other known host but they did rear it on athel in laboratory tests, although it definitely preferred I. dioica; they stated that athel was not a suitable host.

Habib and Hasan (1982) reported that the 43 known species in genus Ornativulva (Lepidoptera: Gelechiidae) are closely associated with Tamarix although a few species also attack plants in the closely related family Frankeniaceae. Of the 13 species (taxons) they collected, 7 were not collected from athel in the field. They collected Ornativulva new species from I. dioica at 3 locations. O. rufipuncta was rare and the other taxons were of uncertain identity and so of uncertain host range. The pterophorid moth, Agdistis arabica, was collected from I. indica and I. salina at 6 locations. It occurs across the Middle East to Israel and Egypt and was relatively abundant in Pakistan.

Habib and Hassan (1982) reported that the gall midges of the genus Psectrosema (Diptera: Cecidomyiidae) also are known only from Tamarix. They investigated 7 unidentified species, none of which were collected on I. aphylla in the field. From this material, Harris (1983) described 4 new species and assigned a new name to a fifth species (Table 69). Habib (1983) provided information on the bionomics of these species. The Pakistani species of Psectrosema were collected on indigenous species of Tamarix that do not occur in North America. Three of these species attacked only one species of Tamarix: P. manii and P. unicornis attack only I. dioica and P. indicum attacks only I. indica. However, P. reticulatum attacks I. hispids, I. androssowii and I. arceuthoides; P. parvum attacks I. dioica and I. indicum. None of the species attacked I. aphylla which was present in many areas.

Since the North American weedy species of Tamarix were not available for testing, the ability of these gall midges to attack them is unknown. All species of Psectrosema were attacked by from 5-10 species of parasites, but some species were very abundant in the field in spite of this. They probably damaged the trees because the galls produce a metabolic sink for nutrients. The Psectrosema species might produce much more damage in North America than in Pakistan if they could escape attack by native North America parasites.

Harris (1983) listed 10 other species of Psectrosema, all known to attack only Tamarix; 5 species were from the Mediterranean area and 5 from Kazakhstan, USSR. All of the species from Kazakhstan were collected from Tamarix ramosissima, the major weedy species in North America; these are P. barbatum, P. mitjaevi, P. dentipes, and P. iliense, and P. noxium. These 5 species would be excellent candidates for further testing.

The host range of the gelechiid gall former Amblypalpis olivierella is somewhat uncertain. In Israel, it attacked all species of Tamarix except I. aphylla but in Pakistan galls similar in appearance were found on I. aphylla but the midge was not identified. In cage tests, it attacked I. indica but not I. aphylla. It was heavily attacked by parasites and predators, and without these it could inflict heavy damage to Tamarix.

Three species of stem borers, Apion tamaricis, Ascalenia pachnodes and Aristolelia ingravata (Table 69), were not collected from athel and appeared specific to Tamarix.

Among the sap-sucking insects (Homoptera and Hemiptera), Habib and Hassan (1982) examined only the membracid Otinotus brevicornis in detail, but it feeds on athel. However, several other species (Table 69) appear worthy of further testing since they have no known hosts other than Tamarix and were not collected from I. aphylla. These include a spittlebug (Cercopidae), tree

hoppers (Membracidae), mealybugs (Pseudococcidae), and jumping plant lice (Aphalaridae and Psyllidae) (Table 69).

In Corrientes Province, Argentina, an entire planting of 1-1/2 to 2-year-old trees was reported killed by the plant pathogen, Botryosphaeria tamaricis (Frezzi 1942). We also observed seriously diseased trees in Buenos Aires Province, Argentina, in 1972 (DeLoach, unpubl. report, USDA-ARS Biological Control of Weeds Laboratory, Hurlingham, Argentina).

Tamarix chinensis, which is one of the three major species in the southwestern U.S. (Baum 1967), or the major species according to Horton (1977), occurs naturally throughout China and in Mongolia, Korea, and Japan (Baum 1978). No explorations for natural enemies of this species, or in this area of other species, have been made.

## XVII. NON-BIOLOGICAL CONTROLS

The rapid invasion of saltcedar along western streams and reservoirs after the 1920's caused great concern among managers and landowners regarding the amount of water consumed, increased flooding and sedimentation, the loss of native riparian vegetation and grazing areas, and the nuisance created in parks and recreational areas. Early control efforts confirmed that saltcedar was a very difficult plant to kill. Mechanical control treatments were effective for only a short period before shoots resprouted from the roots and vigorous growth resumed. Herbicides were more effective where applications reached the root systems in sufficient quantities and shoot resprouting was delayed for a longer period following such treatments. A combination of root plowing and chemical application below the ground surface provided the most effective control (Hollingsworth et al. 1979). Nevertheless, costly annual retreatments were required to maintain the controlled areas.

The largest saltcedar control efforts were along the Gila River in Arizona and the Rio Grande and Pecos Rivers in New Mexico and Texas. Approximately 5,500 acres were cleared on the Gila River but are not currently maintained on an annual basis. A much larger effort was carried out on the Rio Grande and Pecos Rivers where between 60,000 and 70,000 acres of saltcedar were cleared. Plans were to maintain the cleared area free of vegetation in order to preserve the water formerly consumed by saltcedar. At present, however, only about 20,000 acres are maintained on an annual basis (Al Hill, Bur. Reclam., Amarillo, TX, pers. comm., 1989). Much of the cleared land is privately owned and has been leased from the owners for the clearing operations. As the leases have expired, a fewer number were being renewed and, consequently, the amount of acreage maintained free of saltcedar

as decreased substantially in comparison to the original area that was cleared. Court injunctions on behalf of environmentalist organizations concerned about the effects of clearing and channeling on riparian plant communities and wildlife habitat halted control operations during part of the 1970's.

Several smaller control programs are being implemented primarily on national park lands and in wildlife preserves. The areas involved are mostly under 1,000 acres and commonly fall within the 50- to 500-acre range. A more intense program is applied to these lands, where total eradication of saltcedar is sought but other plants are left unharmed.

Chemical or mechanical controls, or a combination of both, have been used most often but fire and inundation have been used and desiccation has been discussed. An estimated 20,000 to 25,000 acres presently are treated annually, at a cost of \$1.0 to \$1.5 million. An overview of various treatments is presented in this section along with comparative costs prepared by Brown (1989). A thorough review of the literature on herbicidal controls was made by Sisneros (1990).

#### A. Herbicidal Controls

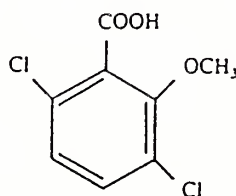
1. Herbicides that Can Be Used to Control Saltcedar. Sisneros (1990) reviewed the herbicides considered by the Bureau of Reclamation's Environmental Sciences Section to be environmentally safe if used in a river basin or near water. They are registered for particular sites such as utility rights-of-way, drainage ditchbanks, and around power plants, fence rows, and storage areas. Although some may not be specifically labeled for saltcedar, they may be used because of exemptions in the Federal Insecticide, Fungicide, and Rodenticide Act as Amended (FIFRAA). In addition, large-scale spraying program are governed by the National Environmental Policy Act (NEPA).

Proposed actions fall into one of three NEPA categories: 1) ~~Categorical~~ Exclusion (does not require further NEPA compliance), 2) an Environmental Assessment will determine if no significant impact will occur or if an Environmental Impact Statement will be required, 3) Environmental Impact Statement (EIS) will be required for a major action with significant impact on the human environment. Full EIS's were prepared for the Rio Grande (Velarde to Caballo Dam) maintenance program of 1975 (Bureau of Reclamation 1977) and the Pecos River Basin Water Salvage Project in 1977 (Fish and Wildlife Service 1981).

Kerpez and Smith (1987) listed 6 herbicides registered for use on saltcedar. Today, only two are labeled specifically for saltcedar (Arsenal and Visko-Rhap A-3D) and 6 other can be used under the exemptions in FIFRAA (Sisneros 1990). Sisneros (1990) provided detailed information on the 8 herbicides that potentially could be used for saltcedar control from small scattered infestation to dense infestations. The information provided below on each herbicide is from Humburg et al. (1989).

a.) Dicamba.

Product name (manufacturer): Banvel (Sandoz)  
 Chemical name: 3,6-dichloro-2-methoxybenzoic acid  
 Molecular structure:



Dicamba controls many annual and perennial broadleaf weeds but does not kill grasses. It is used as a pre-emergence or foliar spray or as granules. As a foliar spray, it is absorbed by leaves and translocated to other parts

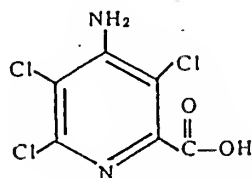
of the plant. Dicamba has properties of an auxin-like growth regulator but the specific mechanism is not clear. It leaches rapidly from the soil and has potential for polluting groundwater. Four granular formulations of dicamba are registered with EPA, ranging from 5.9 to 12.5% active ingredient (ai) but the manufacturer has not registered these projects since 1983-84 for saltcedar control because of concerns about groundwater pollution. A liquid formulation, which was registered for ditchbank use, was recently cancelled for the same reason (Sisneros 1990). Dicamba generally has low-order toxicity to wildlife and fish. Banvel (the dimethylamine salt formulation) has a  $LC_{50}$  of >1000 ml/L to fish,  $LD_{50}$  of >4640 ppm to ducks and quail, and >2000 to 2629 mg/kg acute oral toxicity to rats and rabbits.

b.) Picloram

Product name (manufacturer): Tordon, Grazon (often mixed with 2,4-D) (Dow)

Chemical name: 4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid

Molecular structure:



Picloram is recommended for general woody plant control and most annual and perennial broadleaf weeds; most grasses are resistant. It is available in granular or liquid formulations. Picloram is absorbed by both foliage and roots; it is translocated in the plant and accumulates in new growth. Sorption by organic matter and clay occurs but it leaches through sandy soils and can contaminate groundwater. The label recommends not using it where soils have rapid permeability such as sands and loamy sands. Picloram

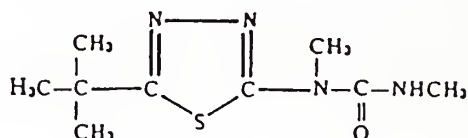
has low-order toxicity to wildlife and fish. Acute oral  $LD_{50}$  to rats, rabbits, guinea pigs and ducks is 2000 to 8200 mg/kg, and to sheep and cattle is >1000 and 7750 mg/kg.

c.) Tebuthiuron

Product name (manufacturer): Spike (Elanco)

Chemical name: N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]  
N,N'-dimethylurea

Molecular structure:



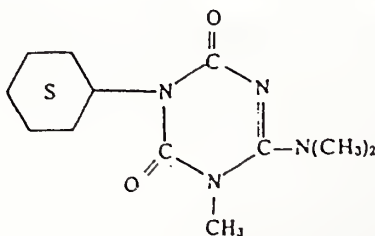
This herbicide is intended for control of grasses, broadleaf weeds and woody plants in non-agricultural areas. It kills a broad spectrum of shrubs and trees and also damages grasses. It is applied as a liquid spray or as granules. Tebuthiuron is readily absorbed through roots and less so through foliage; it is translocated to other parts of the plant. Phytotoxicity suggests that it inhibits photosynthesis. Tebuthiuron binds to clay and organic material in soil and is seldom found below 24" deep; little or no lateral movement occurs. Half life in soil is 12-15 months with 40-60 in. rainfall. It is non-hazardous to birds ( $LD_{50}$  for quail and ducks =>5000 mg/kg) but is toxic to bluegill and trout ( $LD_{50}$  = 112 to 144 mg/l). It is moderately toxic to mammals, with an acute oral  $LD_{50}$  to rats of 400 to >500 mg/kg (Humburg et al. 1989).

d.) Hexazinone

Product name (manufacturer): Velpar (DuPont)

Chemical name: 3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione

Molecular structure:



Hexazinone is used for control of many annual and biennial weeds, woody vines and most perennial weeds and grasses (except johnsongrass) on noncrop-land areas, and is promising for control of aquatic weeds. It is not labeled for saltcedar but can be used under FIFRAA exemptions.

It is readily absorbed through foliage and roots and is translocated upward through the xylem. It appears to inhibit photosynthesis. It is broken down by soil microorganisms. It is water soluble and can move readily with surface water.

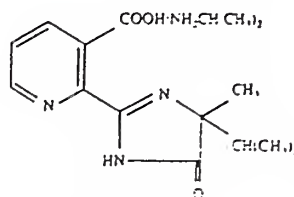
Hexazinone is low in toxicity to wildlife and fish.  $LC_{50}$  to mallard duckling and bob-white quail is  $>10,000$  ppm and for fish (bluegill and trout) is 320 to 420 ppm. Acute oral  $LD_{50}$  to rats = 1690 and to guinea pig = 860 mg/kg. It is not a skin irritant.

e.) Imazapyr

Product name (manufacturer): Arsenal, Chopper, Contain  
(American Cyanamid)

Chemical name: 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid

Molecular structure:



Imazapyr (Arsenal) is specifically labeled for control of saltcedar. However, it is a very broad spectrum herbicide for use on industrial and right-of-way areas to control annual and perennial weeds, deciduous trees and vines. Chopper is for cut stump and basal bark applications. Arsenal is water soluble and Chopper is oil soluble. Imazapyr is very actively absorbed by the foliage and very actively translocated from the soil via the

root system and accumulates in the meristematic tissue. It inhibits a metabolic pathway in the synthesis of three amino acids that is unique in plants. It has excellent soil residual activity and gives pre-emergence weed control for several months. It does not leach in the soil.

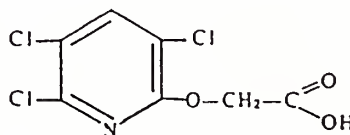
Imazapyr, when used properly, is not hazardous to mammals, fish or birds. The  $LC_{50}$  to trout and bluegill is 110 and 180 mg/L.  $LD_{50}$  to quail is >2150 and to ducks is 5000 ppm and to the honeybee is >25  $\mu$ g/bee (maximum amounts tested). It is irritating to the eyes and mildly irritating to the skin of rabbits (Humburg et al. 1989). It should not be applied in water or irrigation ditches and may not be used in California (Sisneros 1990).

f.) Triclopyr

Product name (manufacturer): Garlon (Dow)

Garlon 3A: water-soluble triethylamine salt and Garlon 4: oil-soluble butoxyethyl ester formulation.

Chemical name: [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid  
Molecular structure:



Triclopyr is recommended for woody plants and broad-leaved weeds, including grazed areas, and non-crop areas; most grasses are tolerant. It causes an auxin-type response similar to the phenoxy herbicides. It is absorbed by foliage, roots and bark and is readily translocated throughout the plant. As a foliar application, the foliage must be thoroughly wetted.

It decomposes in one day in water and in 2-8 weeks in the soil. It is not strongly sorbed in the soil and some leaching may occur in light soils. It should be applied when plants are actively growing and soil moisture is adequate. When used as a stump treatment on saltcedar, some regrowth occurs

that requires retreatment. It has only moderate toxicity to mammals and low toxicity to birds and shows no mutagenic activity but the butoxyethyl ester formulation (Garlon 4) is very toxic to fish. It has little effect on soil microorganisms.

g.) Glyphosate

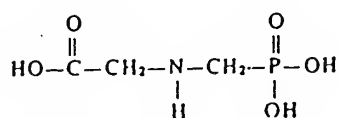
Product name (manufacturer): (Monsanto)

"Roundup" : isopropylamine salt of glyphosate, with in-can surfactant

"Rodeo" : same, without surfactant

Chemical name: N-(phosphonomethyl)glycine

Molecular structure:



Rodeo does not have a surfactant and, therefore, is registered for aquatic use, while Roundup contains a surfactant and is not registered for aquatic sites. Glyphosate is a broad spectrum herbicide and kills many species of annual and perennial broad-leaved plants and grasses. It is absorbed by foliage or green stems and translocated throughout the plant. It is not absorbed through roots or older stems. It has no residual soil activity and is strongly absorbed in the soil, which prevents leaching and movement to groundwater. The mode of action is to inhibit biosynthesis of aromatic amino acids in the plant.

Rodeo has low toxicity to fish ( $\text{LC}_{50}$  = 1000 to >10,000 mg/L) but Roundup is relatively toxic ( $\text{LC}_{50}$  = 3.9 to 110 mg/L). Both have low toxicity to rats ( $\text{LD}_{50}$  = >5000), rabbits ( $\text{LD}_{50}$  = >5000), quail and ducks ( $\text{LC}_{50}$  = >3850 to >4640 mg/kg) but are more toxic to honeybees ( $\text{LD}_{50}$  = >100  $\mu\text{g}$ /bee). Rodeo is non-irritating to skin or eyes but the

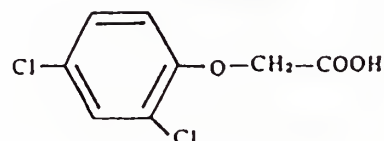
surfactant in Roundup is moderately irritating to both. Glyphosate does not bioaccumulate and is not mutagenic.

h.) 2,4-D

Product name (manufacturer): 2,4-D, Visko-Rhap A-3D; various formulations mixed with other herbicides

Chemical name: (2,4-dichlorophenoxy)acetic acid

Molecular structure:



One formulation, "Visko-Rhap A-3D," is an invert emulsion using the N-alkylamine salt of 2,4,-D, and is specifically labeled for saltcedar. This produces a thick emulsion when mixed with water, which limits drift during application. Several other formulations, though not specifically labeled for saltcedar, can be used under FIFRAA exemptions in non-crop areas and irrigation canals.

2,4-D controls many broad-leaved weeds but does not kill grasses. It has long been used for saltcedar control but is not very effective on mature plants and rarely produces above 80% kill even with repeated applications. It is absorbed through the foliage (ester formulations are absorbed most readily) and translocated to meristematic tissue of shoots and roots. Roots absorb the salt forms most readily. The herbicide causes abnormal growth response and affects respiration, food reserves and cell division but the primary mode of action is not clearly established. In clay soil, 2,4-D is strongly adsorbed but the salt formulations are leached in sandy soils; 2,4,-D undergoes microbial breakdown in warm, moist soils.

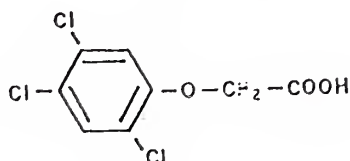
Pure 2,4-D acid is slightly toxic to some fish at 100 ppm. - Acute oral  $LD_{50}$  to rats, guinea pigs and rabbits is 300 to 1000 mg/kg and some formulations may cause skin irritation.

2. Herbicides Previously Used but Now Prohibited. Two herbicides that previously were in widespread usage for saltcedar control were banned by the EPA in October 1983 because of the unavoidable contamination by dioxin in the manufacturing process; these are 2,4,5-T and silvex.

a.) 2,4,5-T (prohibited).

Chemical name: (2,4,5-trichlorophenoxy) acetic acid

Molecular structure:



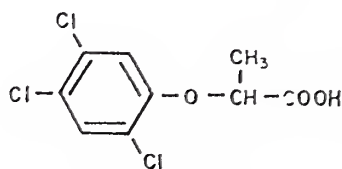
This phenoxy herbicide is very similar to 2,4-D yet it is effective on many woody plants not susceptible to 2,4-D and it kills fewer herbaceous species. For many years, it was the herbicide most widely used for control of woody plants on grazing lands.

b.) 2,4,5-TP (prohibited).

Trade name: Silvex

Chemical name: (2,4,5-trichlorophenoxy) propionic acid

Molecular structure:



This phenoxy herbicide is very similar to 2,4-D and 2,4,5-T but some lawn and aquatic weeds, and especially oaks, are more susceptible to

silvex. Along with 2,4,5-T, it was banned by EPA in October 1983 because of the contaminant dioxin.

3. Past Experience in Herbicidal Control of Saltcedar. Sisneros (1990) reported that the earliest research on herbicidal control of saltcedar was with three closely related phenoxy herbicides, 2,4-D, 2,4,5-T and later with 2,4,5-TP (Silvex). The first experiments were in 1948 by the Bureau of Reclamation near Avondale and Dome, AZ, and along the Pecos River near Carlsbad, NM (Arle 1957, Lowry 1966). These early workers reported "good" results (85% control after 1-1/2 years) but whether "control" referred to canopy kill or whole-plant kill is not clear. These reports led to large-scale clearing efforts during the 1950's, mostly using 2,4-D and 2,4,5-T but these later efforts were much less successful than the early reports.

During the 1960's, approximately 35 herbicides were tested for effectiveness on saltcedar (Arle 1960, Frost 1960, Robinson 1964, Hughes 1968, Sisneros 1990). The best were the acid formulations and especially the PGB (propylene glycol butyl) ester of silvex, at 2 lb. active ingredient (ai) applied in 10 to 80 gal water per acre. Also, granular dicamba gave up to 79% control. Better results were obtained with a 1:1 mixture of 2,4,5-T and silvex ester (Hughes 1966). Best results were obtained when saltcedar was mechanically cleared, burned and the next year the regrowth treated with silvex; spring application of silvex (10 lb ai/A) gave "complete" control whereas fall applications gave only 40% control. However, 2 years later, the 10-lb spring treatment had only a 75% kill.

Quimby et al. (1977) found that saltcedar roots readily assimilated and translocated herbicides. Hollingsworth et al. (1979) developed techniques of applying herbicides with a rootplow that cut the roots at 35 to 60 cm below the soil surface. By this method, several herbicides gave excellent

control but some also killed the grass. The most efficient, and least damaging to grass, were picloram and/or dicamba at 6 or 7 kg/ha, which gave 90 to 97% control up to 4 years after treatment, while maintaining 70 to 90% "infestation" (presumed to = % canopy cover) of the native desert saltgrass; rootplowing alone gave only 40% control and 50% "infestation" of saltgrass, and the untreated check had only 10% "infestation" of saltgrass because of competition with saltcedar.

Granular herbicides gave variable results but in some tests heavy applications (10 lb/acre) of dicamba and picloram gave good control. Timmonds (1963) reported that, in general, young regrowth was easier to kill than older trees. Clearing and burning then followed by applications of 2,4-D or 2,4,5-T gave good control; however, these herbicides used alone never gave satisfactory control with one application and repeated applications gave less than 80% control. During the 1970's, several newer herbicides were tested. Tebuthiuron at 1 to 6 lb/A gave 50 to 97% control after 2 years (Jones et al. 1978).

At El Caballo Reservoir, NM, tebuthiuron and hexazinone used on well-established stands gave better control than dicamba and picloram but gave a maximum of only 70% control (Shrader 1985). Howard et al. (1983) in Utah found that burning followed by treatment of the resprouts with 2,4-D, triclopyr, picloram or silvex in July gave good results. Glyphosate ("Rodeo") gave little control along a canal in New Mexico (Sisneros 1990).

Imazapyr ("Arsenal") was first used for saltcedar control in 1986. On the Bosque del Apache National Wildlife Refuge on the Rio Grande near Socorro, NM, foliar application to "dog-hair" saltcedar didn't kill the plants but did reduce growth. At a nearby farm, a similar treatment also was ineffective but follow-up treatments with a hand applicator killed the

plants, with no resprouting 8 months later (Taylor 1987, Sisneros 1990). Applications of 5% Arsenal with a carpet roller were variable but very effective in some areas. Applications of 2.5% Arsenal with a hand applicator along the Riverside Canal in southern California were totally effective and had a one-year pre-emergent effect (Sisneros 1990). K. Duncan in New Mexico, treated 26 acres of dense saltcedar 20-30 ft tall with aerial applications of Arsenal with good preliminary results; however, 1% granules gave no control (Sisneros 1990). Taylor (pers. comm.) reports that Arsenal is no longer used to clear saltcedar before revegetation at the Bosque del Apache NWF in New Mexico.

Arsenal is rather ineffective in killing legumes; therefore, treatments of saltcedar-mesquite or saltcedar-screwbean areas would possibly kill much of the saltcedar and not damage the mesquite and screwbean too severely, which would be beneficial to wildlife; however, no experiments of this nature were found in the literature. Treatment of saltcedar stands containing cottonwood, willow, quailbush, wolfberry, baccharis or other trees with Arsenal would be destructive to wildlife habitat. Treatment of pure saltcedar stands would not harm other species since other species are not present. However, if these cleared areas were re-established in a mixed stand of saltcedar and native vegetation, then the use of Arsenal as a maintenance treatment would be harmful except to the legumes.

Foliar sprays usually defoliated and often killed the aboveground portion of saltcedar but had minimal impact on the root system where resprouting occurred (Hollingsworth et al. 1979). Basal spray applications are directed towards the base of saltcedar plants. This method was more effective on trees with trunk diameters smaller than 2 in; however, application of herbicides to the cut portion of stumps is much more effective (Hughes 1965).

Application of soil granules and sprays rely upon the subsequent movement of the chemical down to the root zone. This method is susceptible to variations in soil texture and moisture and has highly variable results. Hollingsworth (1973) concluded that herbicide granules or sprays applied to the soil surface were ineffective controls for saltcedar. Once herbicides are applied to saltcedar, the area must be maintained through periodic reapplication of chemicals or mechanical controls and/or allowing revegetation through natural processes or by planting trees or shrub species. According to Hollingsworth (1973), vegetative propagation and regrowth are probably the primary factors which allow saltcedar plants to survive control efforts. Numerous buds are located along the stems and branches of the plant and cover the root crown. In a given year, only a few buds initiate growth and the remaining buds are dormant. When the plant is defoliated by a herbicide treatment, buds previously dormant become active and new growth is stimulated.

Triclopyr has been used as a cut-stump treatment to kill small infestations of saltcedar and to enhance wildlife habitat and surface water supplies. In Anza Borrego Desert State Park, CA, workers use chain saws and hand saws to cut saltcedar vegetation and immediately apply the systemic herbicide triclopyr (the water soluble Garlon 3A) to the newly exposed cut surfaces. All stems, branches and other litter capable of resprouting are removed from the area. After 2 yr of treatment, the average mortality was 77% and increased to 91% with 3 yr of treatment (Comarack 1986). In Death Valley National Monument, CA, the oil-soluble ester formulation (Garlan 4) was used effectively. Triclopyr should be applied to the stumps immediately (within 5 min) after the trees are cut. In the parks, this is often done using volunteer labor to control small areas around springs, etc. (Neill 1983). Hand-cutting would be too expensive on larger areas.

Neill (1989) listed four steps needed for successful control by the cut-stump herbicide method using 2,4-D:picloram or triclopyr:

- 1) Cut stumps within 2 in. of the ground;
- 2) Apply herbicide to stumps within several minutes after cutting;
- 3) Treat entire circumference of cambium layer; and
- 4) Cut and re-treat any sprouts within a year.

These procedures should provide 95% control. Best control was obtained with fall and winter treatments but late spring was the most practical time to search for plants because of their visibility and more pleasant working temperatures. Workers faced a constant risk of heat exhaustion when working during the summer (Neill 1989).

#### B. Non-chemical Controls

1. Mowing and Chaining. Among the earliest controls attempted against saltcedar was mowing the younger shoots and chaining the slightly larger plants. Typical mowing is used to cut vegetation 6 to 8 in. from the ground on plants of 2 in. or less in diameter. Chaining consists of extending a large, heavy chain (similar to the size of an anchor chain) between two crawler tractors which drag it along, breaking off trunks and uprooting entire trees. Chaining is most effective in vegetation up to a maximum of 18 in. in diameter. The tractors are usually equipped with dozer blades or tree crushers to handle the large vegetation. These methods are common and have been successful in areas where new land was being developed for agriculture or where brush was being cleared from rangelands.

However, mowing and chaining killed little, if any, saltcedar. Along the Salt River, AZ, Campbell (1966) mowed saltcedar at 2-, 4-, 8-, and 24-week intervals on different plots throughout the growing season; repeated mowings were required to keep the foliage succulent and within reach of browsing cattle. Results from chaining (Gary 1960) were similar because the subsurface

root crowns were left in place and resprouting of new growth began shortly after treatment. New sprouts grew up to 9-10 ft in a single season.

These methods have been applied to several water salvage projects in Arizona, New Mexico and Texas (Bur. Reclam. 1977, 1979; Culler et al. 1982) but only short-term control has been obtained and frequently, repeated applications are required.

2. Root Plowing. Shallow plowing or disking has been practiced on several control projects (Barclay 1951; Lowry 1962a,b,c,d; Thompson 1956, Watts et al. 1977). The aerial parts of the plant and part of the root structure is destroyed but shoots quickly resprout. Disking is most effective where replacement vegetation is introduced and grows quickly enough to shade and dominate the regrowth of sprouting saltcedar (Graf 1979).

Grubbing or root plowing cuts plant roots below the ground surface usually 1-2 ft deep, with a blade mounted on the back of a crawler tractor. Regrowth usually occurs within 6-12 months unless maintenance controls are used. Several control programs in Arizona, New Mexico and Texas have used plowing and grubbing extensively (Bur. Reclam. 1977, 1979; Culler et al. 1982). Root plowing is the most effective of the mechanical methods but is among the most expensive.

3. Combination Mechanical and Chemical Controls. Mechanical clearing and chemical application have been combined into operations known as "chem-cut" and "chem-plow." With chem-cut, herbicides are applied directly to the stumps during mowing. With chem-plow, a root plow is equipped to inject herbicides directly below the ground surface to saltcedar stumps and roots as they are severed (Hollingsworth et al. 1973).

4. Burning. In view of the rather large accumulation of dead leaves and branches characteristic of many saltcedar stands, controlled burning would

appear to be an inexpensive and effective method of control. However, saltcedar is quite fire resistant <sup>tolerant?</sup> and begins new growth soon after a burn. Other native riparian vegetation such as cottonwood is much less fire resistant and is often killed. In many cases, burning simply increases the dominance of saltcedar over other vegetation.

As an example, in the summer of 1975 on the Green River in Canyonlands National Park, UT, boaters accidentally ignited saltcedar thickets along the banks of the river. Before burning itself out, the fire consumed most of the vegetation over a 10- to 20-acre area. By the summer of 1976, although blackened remains of the fire were still visible, a lush green growth of saltcedar covered the area. By the summer of 1978, the remains of the fire 3 years before were not evident (Graf 1979).

Burning, in conjunction with other control methods such as root plowing or grubbing, is much more effective in delaying regrowth. Nevertheless, regrowth eventually reappears and may be more vigorous than before because of less competition from other species.

5. Desiccation. Since saltcedar is often found in areas where the water table is shallow (3 to 20 ft), workers theorized that lowering of the water table would deprive plants of needed moisture and they would eventually die. When this method was tested in lysimeter tanks (Bur. Reclam. 1973), plant growth was reduced for one year but plants recovered fully the next year. This method has not been implemented in the field. Development of reasonable and effective ways to lower the water table has been a major obstacle due to the fact that pumping is expensive and not always reliable depending upon the specific characteristics of the aquifer (Gary 1965). <sup>not in ref cited</sup>

One unplanned case of desiccation has occurred along the Gila River, AZ, where the water table has declined below the root zone of saltcedar in <sup>Dwy & Campbell 196</sup>

several areas. This has resulted from several dry years along with increased groundwater pumping in the basin. The saltcedar has died out in the places where the roots cannot reach saturated underground zones. Even though this method would appear to be highly effective, it has received only moderate attention because of the many uncontrollable variables involved, especially that other plant species would need moisture for successful revegetation.

6. Inundation. Long-term inundation of saltcedar can be an effective control on lake shores where water levels can be controlled. The exact time requirement has not been precisely determined as varying lengths of inundation have been claimed to be effective. Wiedemann and Cross (1978) observed that saltcedars inundated for a 28-month period incurred a 99% mortality rate. Those inundated for 17 months had a 28% mortality and a 77% mortality when preceded by mechanical clearing. In Arizona, Warren and Turner (1975) found that all mature trees were killed after only 89 to 91 days of root-crown submergence or 43 days of total aerial growth submergence (see Sect. III,G of this report).

As with other control methods, saltcedar begins reinvading once the area is no longer inundated. Periodic inundation has been coordinated with the management of wetland areas with some degree of success (Kerpez and Smith 1987) in the control of saltcedar. Nevertheless, along most rivers, inundation is incompatible with water management objectives and cannot be implemented, especially in areas where flood control is part of the management function.

### C. Costs of Control

Brown (1989) calculated the cost of various methods of controlling saltcedar based on average costs of the various components of the program, over a 20-year period with 8% interest, with expected duration of treatments

based on past experimental and practical results, and updated to 1988 prices. Component costs averaged \$300/acre for land clearing (cutting, plowing, grubbing, disking, piling, and burning), \$15 for rotary mowing, \$43 for root-plowing, \$82 for chemical treatment (\$155/gal @ 2 qt/acre + aerial application), \$95 for chem-cut, \$123 for chem-plow, and \$300 for revegetation.

Brown (1989) then calculated costs for 8 different control options that included the more common and effective methods currently in use. He found that all current treatments that were effective included clearing plus a herbicidal applications and/or root-plowing. His costs for revegetation were based on re-establishment of grasses. Revegetation costs ranged from \$150 to over \$8,000/acre (see Sect. VI,D,2,e, this report) but he assumed that if costs exceeded \$300 per acre then revegetation would not be done. Present value of these control programs ranged from \$545 to \$754/acre, or an average annual cost of from \$55 to \$77 per acre over the 20-year program with an 8% interest rate (Table 70). He suggested that clearing plus chem-plow (Treatment 5) was the most cost effective.

The cost for control of the approximately 60,000 acres along the Pecos River for 20 years would have a present value of \$32 million to \$45 million at 1989 prices. Although considerable amounts have been expended on conventional methods, effective control of saltcedar has not been achieved. Cost is one of the principal factors in the search for other control methods that are much more cost effective.

#### D. Conclusions.

No satisfactory control has yet been developed for saltcedar in non-cultivated riparian areas for two primary reasons. First, the plant is difficult to kill; it resprouts readily from crown buds if the top is killed and from roots following plowing. Second, the multi-use values of the

Table 70. Costs of combination mechanical and chemical control of saltcedar (from Brown 1989).<sup>a/</sup>

Treatment <sup>b/</sup>		Present value (\$)	Avg. ann. cost (\$)
1	Clearing	545	55
2	Clearing + root plow	547	56
3A	Clearing + chemical	708	72
3B	Clearing + chemical + revegetation	754	77
4A	Clearing + chem-cut	609	62
4B	Clearing + chem-cut + revegetation	623	63
5A	Clearing + chem-plow	571	58
5B	Clearing + chem-plow + revegetation	649	66

<sup>a/</sup> Assumes an 8% discount rate and a 20-year program.

<sup>b/</sup> Treatment explanations:

- 1 Includes two maintenance mowings per year.
- 2 One maintenance mowing in third year and two per year thereafter.
- 3A One herbicidal application per year during first 4 years, one application each 3 years thereafter.
- 3B Same as 3A for first 5 years, revegetated in fifth year with no further herbicidal applications.
- 4A Chem-cut during first, third, sixth, ninth, thirteenth, and seventeenth years.
- 4B Chem-cut during first year only, revegetated in second year.
- 5A Same as 4A except chem-plow.
- 5B Same as 4B except chem-plow.

habitat for wildlife, grazing, irrigation water, etc., preclude controls that kill all the vegetation or even all species of trees and shrubs. Also, the controls that have been developed are very expensive and require repeated re-applications to maintain control.

The various mechanical methods, such as mowing, bulldozing, and root plowing, control saltcedar only temporarily; they require frequent retreatments, are very expensive, and are very destructive to the beneficial vegetation and wildlife habitat. Fire kills only the top of the plant and plants regrow to 2-3 m the next year; also, fire kills many beneficial species outright, thus giving saltcedar a strong competitive advantage.

Several herbicides give moderate to good control of saltcedar but, again, good control nearly always requires more than one application and the saltcedar still regrows from roots or seed and requires retreatment. In 1987, 6 herbicides were registered for saltcedar control. Today, only two are registered specifically for saltcedar; these are an invert emulsion of the N-alkylamine salt of 2,4-D (Visko-Rhap A-3D) and imazapyr (Arsenal). In addition, six other herbicides could be used under the exclusion provisions of FIFRAA although they are not specifically labeled for saltcedar. These are dicamba (Banvel), picloram, tebuthiuron (Spike), hexazinone (Velpar), triclopyr (Garlon) and glyphosate (Roundup and Rodeo). Two herbicides that were long used with moderate success, 2,4,5-T and 2,4,5-TP (Silvex), were banned by EPA in 1983 because of unavoidable contamination by dioxin in the manufacturing process.

Most of the 8 herbicides that may be used are broad spectrum and kill many woody plants, broad-leaved herbs and grasses, though dosages and application methods often can be adjusted to minimize damage to certain groups of plants. Tebuthiuron and imazapyr kill most grasses, broadleaved weeds and woody plants, although imazapyr is less toxic to legume. Hexazinone and glyphosate kill most grasses and broadleaved herbs but are less damaging to woody plants. Of those that kill woody plants well (dicamba, picloram, tebuthiuron, imazapyr and triclopyr), all also kill broadleaved herbs and only dicamba, picloram and triclopyr spare most grasses.

Of the two herbicides specifically labeled for saltcedar control, imazapyr (Arsenal) would also kill nearly all other plants (with less damage to legumes) and 2,4-D (Visko-Rhap A-3D) would also kill most broadleaved herbs and many woody plants but not grasses. Trials indicate that imazapyr

usually gives good control of saltcedar. In past experience, 2,4-D has not been very satisfactory but the invert emulsion appears to be more effective.

Triclopyr (Garlon), which is effective as a stump application, is safe to other vegetation because of the method of application, but this is too labor intensive and expensive except in special cases of small infestations. Effectiveness is increased by using herbicides together with mechanical controls or fire but this greatly increases the cost and also the harm to other vegetation.

### XVIII. BIOLOGICAL CONTROL

The use of insects or plant pathogens to control saltcedar has been proposed by several workers (Hopkins and Carruth 1954, Watts et al. 1977, DeLoach 1981, DeLoach et al. 1986, DeLoach in press). The method would appear to be highly appropriate for saltcedar if the conflicts of interest can be resolved.

#### A. Philosophy and History

Biological control is a proven technology that has been used effectively in several countries for many years (Huffaker 1959, Goeden 1978, Julien 1982, Kelleher and Hulme 1984). The method has been applied mostly in rangelands to control introduced weeds and has been used to successfully control several woody species. The object of biological control is to reduce the abundance of the target weed to a lower level so that the damage caused, and the cost of present controls, can be reduced or possibly eliminated. The objective is not the eradication of the target weed. Neither the complete eradication nor the reduction of a plant to a rare or endangered status has ever occurred in previous bio-control projects.

The theory and methodology are well developed for all the various aspects of a control program, including the selection of appropriate target weeds (DeLoach 1981, DeLoach 1984), the discovery of foreign control agents (Sands and Harley 1981, Wapshere 1981), the selection of effective control agents (Harris 1973, Goeden 1983, Wapshere 1985), host specificity testing (Zwölfer and Harris 1971, Wapshere 1974), and the evaluation of results after release (Huffaker 1959, Wapshere 1975, Goeden and Louda 1976, Harris 1979).

Harris (1988) pointed out that both the application of biological control or withholding it can influence the abundance of native species with which

weeds compete. He found that dense stands of a given species usually exist because of a lack of herbivory and are inherently unstable. In several cases, species diversity increased greatly when a herbivore was added or decreased when a herbivore was removed. In California, the number of plant species increased by 35% following biological control of Klamath weed (Huffaker and Kennett 1959).

Harris (1988) also postulated that rare plant species had little risk of being made more rare by the attack of introduced biological control agents because the density-dependent nature of the herbivore-host plant relationship made attack on a low-density plant very unlikely. In fact, he suggested that rare and endangered plant species faced far greater risk of extirpation from competition of too abundant weeds, or the herbicides used to control them, than from an introduced biological control agent. The effect of weeds that occur in dense stands is to decrease plant diversity, with the weed occupying most of the plant community (Harris 1988) and excluding native plants and animals from their habitat. Harris (1988) cited several cases in the U.S. where rare species were becoming more rare because of invading weeds. In Australia, over 50 plant species are considered endangered because introduced weeds out-compete them (Bell 1983). In Germany, 89 of 589 rare plants are declining as a result of herbicide application (Sukopp and Trautman 1981).

Conflicts of interest between groups who want a weed controlled and others who do not want it controlled must be carefully considered in the initial stages of a program (Andres 1981a,b, DeLoach 1978, DeLoach 1981). The advantages, disadvantages, and ecological consequences of releasing any organism or of controlling any weed are under careful scrutiny by the Technical Advisory Group for the Introduction of Biological Control Agents of Weeds (TAGIBCAW) of the Animal and Plant health Inspection Service (APHIS)

of the U.S. Department of Agriculture. ~~This is a group with broad scientific~~ expertise that regulates the testing and introduction through all stages of a control program (Klingman and Coulson 1982, Coulson and Soper 1989).

Biological control of weeds by the purposeful introduction of exotic insects was first used in Ceylon (Sri Lanka) in 1865. In Australia, after 25 years of research, the highly effective Cactoblastis moth was found and released in 1928 and gave outstanding control of prickly pear cactus within 5 years. Research and introduction into Hawaii between 1903 and the 1960's resulted in the control of several weeds, among them lantana, prickly pear, puncture vine, pamakani and others.

Biological control of weeds was first used in continental North America in 1944 by introducing a European leaf beetle (previously developed by Australia) to control the poisonous St. Johnswort (Klamath weed) in California; it provided outstanding control within 5 years. Since that time, releases of European insects by the USDA and the Canadian Department of Agriculture (CDA) have resulted in good control of puncturevine, tansy ragwort and musk thistle. In the late 1960's and 1970's, insects released by the USDA controlled alligatorweed and water hyacinth in aquatic areas of the Southeast. Several promising projects are currently underway by the USDA and the CDA in western North America, such as yellow starthistle, Russian knapweed, spotted knapweed, and leafy spurge. In the southwestern U.S., insects have been released by the USDA to control snakeweed and a crop weed, field bindweed. In the Southeast, projects are underway to control hydrilla, waterlettuce and Melaleuca tree.

Up to 1980, worldwide, 192 exotic organisms (166 insects, 5 mites, 1 nematode, 11 fungi, and 9 fish) had been released to control 86 weeds (Julien 1982). Control agents most often used are insects. Foliage-feeders

have often been used successfully, but stem borers, flower and seed feeders and gall formers also have been successful. A few plant pathogens, nematodes and mites have been used.

Benefit-cost ratios achieved with herbicidal and mechanical controls have seldom exceeded 3:1 for weeds in rangelands and frequently, with increased costs in recent years, such treatments do not produce a positive return and frequently are not used to control serious weeds. In cases of substantial or complete success with biological controls, benefit-cost ratios commonly exceed 50:1 and may exceed 1000:1 (Andres 1977, Harris 1979). This is because costs are independent of the area treated or controlled (DeLoach et al. 1966). The control agents need to be released at only a few sites, after which they increase and spread on their own and actively seek out the weed.

Biological controls are extremely species specific, unlike mechanical and herbicidal controls which usually kill many and sometimes all the plants. This high specificity is very desirable in natural areas where only one invading weed is a problem and the other plants are beneficial in the ecosystem. It also has no poisonous effect on wildlife or fish and causes no pollution of the environment.

In a review of past biocontrol of weeds projects, Harris (1988) concluded that the effects have been to replace weed stands with diverse plant communities, with the weed species remaining as a minor component of the plant community.

#### B. Potential for Biological Control of Saltcedar

Saltcedar appears to be one of the most appropriate weeds to be evaluated for biological control potential in the U.S. for several reasons.

- 1) It is a long-lived perennial in a stable ecosystem, where control agents would not be disturbed or destroyed by agronomic practices.

2) It causes great damage to the ecosystem through the displacement of native plant communities and degradation of habitat for many species of songbirds, game birds, small mammals, and game animals. Species richness (both plant and animal) is lower in saltcedar stands than in almost any other plant community. It appears to use more water than the native vegetation it replaced, contributing to water shortages for agriculture, municipalities, native plant communities and wildlife; and grazing for livestock is seriously reduced.

3) It is not closely related to any native North American plant (none in the same plant family) and is closely related to only one introduced beneficial plant (athel, or Tamarix aphylla). Therefore, the probability that introduced control agents would attack non-target plants is extremely small.

4) Many promising and apparently host-specific insects are known and have been partially tested that attack saltcedar within the area of its native distribution in southern Asia. Several insects are known there that attack saltcedar but not athel. Many of these insects occur in areas (Israel, Pakistan, southern USSR, People's Republic of China) where the USDA-ARS has cooperative relationships for obtaining and testing control agents.

#### C. Procedures for Implementing Biological Control of Saltcedar

If biological control were to be approved as a viable option for controlling saltcedar, the following mode of operation would be followed:

1) Request would be made to the Technical Advisory Group for the Introduction of Biological Control Agents of Weeds (TAGIBCAW) for an opinion on and resolution of the conflicts of interest involved between the beneficial uses and harmful effects of saltcedar. Copies of this report are being forwarded at this time to TAGIBCAW for this purpose. If a favorable reply is received, the following procedures will be followed:

2) Contact will be made to the USDA-ARS Biological Control of Weeds Laboratory, Rome, Italy (through the ARS Staff Scientist for Biological Control, BARC-West, Beltsville, MD) with a research plan for implementation. (A preliminary plan has already been submitted.)

3) The ARS Rome Laboratory will contact cooperators in Israel and Pakistan to arrange collection and shipment of known candidate insects to Rome for host-range testing. Additional exploration for control agents will be made in the Mediterranean area through the Rome Laboratory and in the People's Republic of China through the ARS-China Biological Control Lab in Beijing; preliminary host-range testing may also be done in

Beijing or in the ARS Biological Control Lab in Seoul, Korea. Additional exploration, preliminary testing and collection of control agents may be made through cooperating laboratories in Pakistan or in the USSR through the recently implemented US-USSR biological control initiative.

4) After testing, a complete report of the test results will be sent from the ARS overseas laboratories to TAGIBCAW requesting authorization to introduce the candidate control agent into Quarantine in the U.S. for further testing. If approved, APHIS will issue a permit for shipment of the candidate control agent to the Quarantine Facility, Grassland, Soil and Water Research Laboratory, USDA-ARS, Temple, TX.

5) At the Temple, TX Quarantine facility, additional host range testing will be performed, using especially plants from the U.S. that were not available for testing overseas.

6) When the quarantine testing is completed, a report of the test results will be forwarded to TAGIBCAW requesting authorization to release the control agent into the field within the U.S. Copies of this petition are forwarded by TAGIBCAW to appropriate agencies in the Canadian and Mexican governments. If approval is obtained from TAGIBCAW for release, appropriate forms will be filed through the state Departments of Agriculture (probably one or more of Texas, New Mexico, Arizona, California, Utah, Colorado, or Wyoming) to APHIS requesting authorization to release the control agent in the field in that state(s). If approved, APHIS will issue permits for release.

7) Additional requests will be made to the ARS overseas laboratories for shipments of the control agent to the Temple Quarantine Facility. In quarantine, these insects cultures will be "cleaned" of any extraneous organisms (parasitoids, predators, or pathogens) by rearing through a partial or complete (or more than one) generation as needed. If needed, the clean cultures will be increased in quarantine to obtain numbers sufficient for release.

8) Releases in the field will be made in the proper habitats and climatic zones and at the proper times of year and in sufficient numbers to insure establishment. Sites will be sought where absolute protection can be guaranteed against disturbances that will destroy the control organisms, such as burning, bulldozing, mowing, herbicide treatments, insecticide application, etc. Such protection is normally required for 3-5 years until the insects are firmly established and are dispersing freely to other areas.

9) Periodic surveys and measurements of control agent populations and damage to or control of saltcedar will be made for several years after release, to follow the progress and to determine the degree of control obtained.

10) Additional natural enemies will be tested and released according to the above procedures as needed, and as appropriate candidates can be found overseas, until the desired degree of control is obtained. Before the introduction of each additional control agent, TAGIBCAW and all concerned agencies should review the degree of control already obtained and ascertain whether, or how much and what type, of additional control is desired. It is here suggested that more than 80% control should not be pursued without a careful review of the economic and ecological consequences and a determination that additional control would be desirable.

## XIX. ECONOMIC ANALYSIS

Brown (1989) conducted an economic analysis of the harmful, beneficial and ecological values of saltcedar and the projected effects of a 50% or 90% effective biological control program. This project was funded by the Bureau of Reclamation to Great Western Research, Phoenix, AZ, separately from the compilation and review of the literature of the present report. Personnel of the two projects worked cooperatively during the investigations. The economic analysis was presented in the form of a report to the Bureau of Reclamation, Lower Colorado Region, Boulder City, NV (Brown 1989). Details of this analysis have been summarized in the preceding sections of the present report, as applicable. A summary of the economic analysis of Brown (1989) is presented in this section, in the form of separate economic, environmental and social accounts. Separate accounts are necessary because of the difficulty in converting subjective ratings for environmental and social values to monetary values.

The Economic Account displays the beneficial and adverse impacts in monetary values. These values are based on 1988 prices and represent the annual impacts over a 20-year period.

The Environmental Account displays the beneficial and adverse impacts in nonmonetary units. These units express the kind of impacts under existing conditions and the direction of the impact, in terms of whether existing conditions are improved or further degraded, under the 50 and 90% levels of saltcedar control. The Social Account displays the beneficial and adverse impacts in the same format as the Environmental Account but relates the results to selected socio-economic factors.

### A. Economic Account

In the economic account, annual expected impacts are assembled for each area analyzed in this study (Table 71). In certain areas, the results depend upon data with a range of possible values and, therefore, a range of possible results are displayed. The values in the table represent the annual impacts expected to occur over a 20-year program which have a total net positive value of \$22.0 million for the 50% level of control and from \$40.3 million to \$62.0 million for the 90% level. The present value would be approximately \$216 million for the 50% program and between \$395 million and \$608 million for the 90% level of control using an 8% interest rate.

Table 71. Economic account for 50 and 90% saltcedar control programs (from Brown 1989, Table 15.1).

Impacted area	Net annual impacts <sup>a/</sup> (millions of dollars)	
	50% Program	90% Program
Water use	0.00	0.00 to 23.0
Livestock forage	0.25	0.45
Flooding	23.00	40.00
Sedimentation	(0.50)	(1.00)
Recreation	0.70	4.50
Dove hunting	(0.70)	(1.40)
Honeybees	0.00	(1.00) to (2.30)
Ornamentals	0.70	(1.30)
TOTALS	22.05	40.25 to 61.95
PRESENT VALUE <sup>b/</sup>	216.49	395.18 to 608.23

<sup>a/</sup> Annual estimated values for 20-year program using 1988 prices. Numbers in parenthesis signify positive impacts of saltcedar, negative impacts of control.

<sup>b/</sup> 8% interest rate.

In economic terms, the impacts of saltcedar control are overwhelmingly positive based upon the results of the analysis. The estimated breakeven

point for a 50% control program would be \$22.0 million per year which would more than justify the planned one-time expenditures of \$1.0 to \$2.0 million for the biological control method. Although the 90% level of control would be more costly, the estimated annual benefits are also higher, between \$40.0 and \$62.0 million.

#### B. Environmental Account

The Environmental Account is based upon a subjective evaluation of the impacts for both levels of saltcedar control in terms of whether baseline conditions are enhanced, incur no changes or are adversely impacted. Positive impacts signify that saltcedar control will improve upon baseline conditions and negative impacts indicate an expected adverse result upon baseline conditions. The general impacts are summarized in the following paragraphs.

Water Use: Positive impacts. Overall water quality will improve due to: 1) an increase in water that will dilute flows in many areas, and 2) a decrease in point sources of salinity, although saltcedar is only a minor contributor in this area.

Livestock: Positive impacts. Establishment of native vegetation in areas invaded by saltcedar will provide additional grazing forage to livestock.

Flooding: Positive impacts. Since saltcedar removal will increase channel capacity, less area will be affected by flood events of similar magnitudes under baseline conditions. This will provide an increase in security and decrease flood damages to the environment. It is noted that occasional mild flooding of riparian zones may also result in beneficial impacts to the environment.

Sedimentation: Negative impacts. Removal of saltcedar will allow more sediment to flow into reservoirs which infringes upon active capacity.

Recreation: Positive impacts. Improved access, increased wildlife, decreased foul odors and salt accumulations, and larger recreational areas will generally be the impacts to the recreationalist. Minor adverse impacts may result in areas where saltcedar is

the only vegetation which provides greenery and shade. However, the positive impacts are much greater than the negative impacts.

Dove Hunting: Negative impacts. The white-winged dove will be adversely impacted due to the decrease in habitat which will, in turn, affect population numbers.

Honeybees: Negative impacts: Minor negative impacts will occur in the honeybee industry due to dependence upon saltcedar during times when other pollen sources are scarce. Reductions in colony numbers may result but are not likely.

Windbreaks: No impacts. Since most windbreaks are *I. aphylla* which is not affected by the control program, windbreaks will not be affected.

Soil Stabilization: No/Negative impacts. No impacts on soil stabilization will occur except in riverine areas where a decrease in saltcedar will moderately increase bank erosion in isolated reaches.

Ornamentals: Positive impacts. The control program will affect *I. chinensis* which is used sparingly as an ornamental in the Southwest. Although monetary impacts will be incurred for plant replacement, a general improvement in species will occur.

Wildlife: Positive impacts. With the exception of a few species, wildlife will be positively affected by improvements in habitat.

Plant Community: Positive impacts. Native species whose habitats have been invaded with saltcedar will have the opportunity for reestablishment.

A general summarization of environmental impacts from a saltcedar control program is that more positive effects result than negative effects. The two areas most benefited are wildlife and the plant community, where all native plants would be enhanced. Only four areas are expected to incur adverse impacts: sedimentation, dove hunting, honeybees, and soil stabilization. White-winged doves will incur moderate impacts as populations adapt to a modified habitat. Only minor impacts will occur in the other three categories. Mitigation plans could be implemented to minimize adverse impacts

In all adversely impacted areas except sedimentation where it is likely that no action would be taken due to the minimal amounts involved and the nature of the impacts. The detailed Environmental Account is present in Table 72.

Table 72. Environmental account for 50 and 90% saltcedar control programs (from Brown 1989, Table 15.2).<sup>a/</sup>

Impacted area	Status under baseline conditions	Expected effects of control	
		50%	90%
Water use	-1	0	+1
Livestock forage	-1	0	+1
Flooding	-1	+1	+2
Sedimentation	+1	0	-1
Recreation	-2	+1	+2
Dove hunting	+1	0	-1
Honeybees	+1	0	-1
Windbreaks	0	0	0
Soil stabilization	+1	0	-1
Ornamentals	0	+1	-1
Wildlife			
REPTILES:			
Mexican garter snake	0	0	0
Narrowhead garter snake	0	0	0
MAMMALS:			
Peninsular bighorn sheep	-2	+1	-2
BIRDS:			
Baird's sparrow	0	0	0
American bittern	0	0	+1
Gray hawk	0	0	+1
Swainson's hawk	0	0	0
Common black hawk	0	0	+1
Great egret	0	0	0
Belted kingfisher	0	0	0
Yellow-billed cuckoo	0	0	-1
Western yellow-billed cuckoo	-1	0	+1
Northern gilded flicker	0	0	+1
Black-bellied whistling duck	0	0	-1
Snowy egret	0	0	0
Willow flycatcher	+1	0	-1
Willow flycatcher ( <u>extimus</u> )	0	0	0
Peregrin falcon	0	0	0
American peregrin falcon	0	0	0

Table 72. contd. 1

Impacted area	Status under baseline conditions	Expected effects of control	
		50%	90%
Whooping crane	-1	0	+2
Bald eagle	0	0	+1
Mississippi kite	+1	0	-1
Least bittern	0	0	+1
Black rail	0	0	0
Black rail ( <u>contorniculus</u> )	0	0	0
Gila woodpecker	0	0	+1
Elf owl	0	0	+1
Osprey	0	0	0
Brown pelican	0	0	0
California brown pelican	0	0	0
Olivaceous cormorant	0	0	0
Yuma clapper rail	0	0	0
Least tern	0	0	0
Interior least tern	0	0	0
California least tern	0	0	0
Bell's vireo	0	0	+1
Arizona Bell's vireo	0	0	0
Least Bell's vireo	0	0	+1
Plants			
Cat-claw acacia	-1	0	+1
Boxelder	-1	0	+1
Four-wing saltbush	-1	+1	+2
Quail bush	-1	+1	+2
Seepwillow	-1	+1	+2
Redbud	-1	0	+1
Red-osier dogwood	-1	0	+1
Apache plume	-1	+1	+2
Ash	-1	0	+1
Wolfberry	-1	0	+1
Common reed	-1/0	+1	+2
Arizona sycamore	-1	0	+1
Narrowleaf cottonwood	-1	0	+1
Fremont cottonwood	-1	0	+1
Plains cottonwood	-1	0	+1
Western honey mesquite	-1	0	+1
Screwbean mesquite	-1	+1	+2
Chokeberry	-1	0	+1
Goodding's willow	-1	0	+1
Black willow	-1	0	+1
Scrub willow	-1	0	+1
Bulrush	-1/0	+1	+2
Buffalo-berry	-1	0	+1
Alkali sacaton	-1	0	+1
Arrowweed	0	+1	+2

Table 72. contd. 2

Impacted area	Status under baseline conditions	Expected effects of control	
		50%	90%
Cattail	-1/0	+1	+2
Columbine	0	0	0
Columbine ( <i>formosa</i> )	0	0	0
Black maidenhair spleenwort	0	0	0
Rydberg thistle	0	0	0
Virgin thistle	0	0	0
Saw grass	0	0	0
Fleabane	0	0	0
Flaveria	0	0	0
Redrock tarweed	-1	+1	-2
Red monkeyflower	0	0	0
Eastwood monkeyflower	0	0	0
Hop hornbeam	0	0	0
Primrose	0	0	0
New Mexican raspberry	0	0	0
Lady's tresses	0	0	0
Death camas	0	0	0

a/ -2=very adverse; -1=adverse; 0=no impact; +1=beneficial; +2=very beneficial.

### C. Social Well-being Account

Brown (1989) prepared the Social Well-being Account (SWB) to analyze the probable future impacts of implementing the different saltcedar control programs as they beneficially or adversely affect people and communities. Impacts result from changes brought about by implementing a plan. These changes can improve upon existing conditions, have no effect upon existing conditions, or worsen existing conditions in terms of how people and communities are impacted. Three sets of future conditions were analyzed in the present SWB: baseline (existing) conditions; 50% control; and 90% control.

The three sets of future conditions were analyzed across five general components in the socio-economic sector as described by Fitzsimmons et al. (1975):

- Individual and personal effects;
- Community and institutional effects;

Area and socio-economic effects;  
 National and emergency preparedness effects;  
 Aggregate and social effects.

Although a number of evaluation categories were included within each component, only selected categories apply to the present study. For example, within the Individual and Personal Effects component, three categories were evaluated:

- 1) Life, Protection and Safety: Property and life loss related to the presence and control of saltcedar;
- 2) Attitudes, Beliefs and Values: Resident expectations of what will be the impacts of each alternative on the local environment and economy, and their perceptions of government agencies (federal and state) that are involved in implementation; and
- 3) Environmental Considerations: Changes in the environment as they affect residents' mental and physical well-being, i.e., aesthetic quality, pollution levels (odor, land, water), accessibility to scenic or recreational sites, land and water use.

The Community and Institutional Effects component involved only one category:

- 1) Recreation: This category will be analyzed in terms of annual use of (attendance at) public recreation facilities.

The Area and Socio-Economic Effects component contained two categories for analysis:

- 1) Employment and Real Income: Changes for individuals and society; and
- 2) Economic Base: Changes in output and composition.

The National and Emergency Preparedness Effects component considered three categories:

- 1) Water Supplies: Changes in amount of water available and quality;
- 2) Water Transportation: Changes in the accessible areas; and

3) International Treaty Obligations: Changes in the ability to satisfy treaty requirements.

The Aggregate Social Effects component considered only one category:

1) Changes in Social Well-being: Enhanced security of life and property through reduction in water-related risks.

The estimated impacts for each area affected by saltcedar control were analyzed using the SWB Account categories described above and the results are summarized in Table 73. Existing impacts of saltcedar are reflected in baseline conditions and the impacts on baseline conditions are reflected in the 50 and 90% levels of control. A description of the rationale underlying the type and degree of expected impacts shown in Table 73 are presented in the following paragraphs.

Table 73. Social well-being account for 50 and 90% saltcedar control programs (from Brown 1989, Table 15.3).<sup>a/</sup>

Impact category	Baseline conditions <sup>b/</sup>					50% control <sup>b/</sup>					90% control <sup>b/</sup>				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
Water use	-1			-1		0			0		+1				+1
Forage			-1					0					+1		
Flood control	-1				-1	+1				+1	+1				+1
Sedimentation			+1	-2				-1	+1				-1	+2	
Recreation	-1	-1	-1			0	+1	+1			+2	+1	+1		
Doves		+1	+1				0	0				-1	-1		
Honeybees			+1					0					-1		
Windbreaks			+1					0					0		
Soil stabilization			+1					0					0		
Ornamentals	-1		0			0		-1			+1		-1		
Wildlife	-1	-1				+1	0				+2	+1			
Plant life	-1					+1					+2				
Mexico			0					0				0			

<sup>a/</sup> -2=very adverse; -1=adverse; 0=no impact; +1=beneficial; +2=very beneficial. Numbers do not appear in the cells where saltcedar has no impact or a particular category.

<sup>b/</sup> I=Individual and Personal Effects; II=Community and Institutional Effects; III=Socio-Economic Effects; IV=National Emergency Preparedness Effects; V=Aggregate Social Effects.

Water Use. Component I deals with attitudes and expectations. Under baseline conditions, the general belief is that saltcedar consumes water that could otherwise be put to a beneficial use. The 50% program will slightly improve attitudes and expectations, while the 90% program will result in a marked improvement in this area. Component IV deals with international treaty obligations which, in view of the fact that saltcedar uses water, any decrease in the plant population will perhaps ease the strain on resources in meeting obligatory requirements (especially along the Colorado River).

Livestock Forage. Component II deals with the economic base. Under baseline conditions, saltcedar has displaced native vegetation which served, to a limited extent, as forage. The 50% program will not affect baseline conditions; however, the 90% program will provide the opportunity for native grasses and vegetation to become reestablished and some increase in livestock forage availability will occur in selected areas.

Flood Control. Component I deals with increased flooding under baseline conditions due to saltcedar obstructing channels. Channels will obtain greater capacity and the danger of flooding will be reduced as the presence of saltcedar is decreased under both the 50 and 90% programs. Component V relates to an enhancement of the security of life through reduced risks from flooding. Both the 50 and 90% programs will lessen these risks compared to baseline conditions.

Sedimentation. Component III reflects the positive baseline conditions where saltcedar traps sediment that would otherwise be deposited in reservoirs. Both the 50 and 90% programs would result in moderately increased sedimentation, adversely affecting baseline conditions. Component IV would deal with clearer waterways which can become extremely clogged under baseline conditions. Significant improvements in baseline conditions will be made by both the 50 and 90% programs.

Recreation: Component I reflects the effects on access to recreational facilities and sites by saltcedar under baseline conditions. No improvement is expected under the 50% program, while significant improvement is anticipated under the 90% program. Component II deals with increased use of recreational areas. Baseline conditions show adverse affects by saltcedar which are expected to become improved under both the 50 and 90% programs. Component III relates to the economic base for recreational activities. The presence of saltcedar under baseline conditions tends to reduce visitation and associated expenditures. As the 50 and 90% programs decrease the presence of saltcedar, visitor usage will increase and so will expenditures in the local economy.

Dove Hunting. ~~Component II relates to the favorable~~ saltcedar habitat for white-winged doves which encourages hunting in several areas. The 50% program will have no effect on baseline conditions; however, the 90% program will cause adverse impacts and hunting activities are expected to decline. Component III deals with the economic base which is favorably impacted by baseline conditions. No change in existing conditions are expected under the 50% program. The 90% program will have an adverse impact on the economic base due to decreased hunter use expenditures.

Honeybees. Component III relates to the economic base which, under baseline conditions, is positively impacted in selected sites where honeybees rely on saltcedar pollen for colony maintenance during periods when other pollen sources are scarce. The 50% program would have no impact on baseline conditions while the 90% program would cause possible increased costs to owners and/or lower output.

Windbreaks. Component III relates to the economic base. Under baseline conditions, windbreaks (most are athel) preserve natural resources and prolong the life of assets through protection from the elements. Since windbreaks are primarily I. aphylla, there will be no impacts from either the 50 or 90% programs.

Soil Stabilization. Component III deals with preservation of the economic base through protection of natural resources. Baseline conditions have positive effects on stabilizing river banks and soils. Due to the fact that root systems will remain until replacement vegetation becomes established, the 50 and 90% programs will have no impact upon existing conditions.

Ornamentals. Component I relates to aesthetic quality which is adversely affected under existing conditions. The 50% program will cause no changes in these conditions, while the 90% program will cause an improvement in aesthetic quality due to the fact that much of the I. chinensis will be replaced. Component III deals with the economic base. Under both the 50 and 90% programs, owners will incur additional costs to replace saltcedar used as ornamentals with other species (usually an improvement) which are considered adverse impacts. Although owners are faced with increased outlays, the local economic base is stimulated somewhat through increased sales.

Wildlife. Component I relates to environmental concerns. Under baseline conditions, the majority of wildlife is adversely affected by saltcedar through loss of native habitat. The 50% program will provide an improvement and result in positive impacts. The 90% program will result in significant positive impacts by restoring native habitat.

Component II deals with recreational use to observe wildlife. Visitation is adversely affected by baseline conditions because fewer wildlife can be observed in saltcedar habitat. The 50% program is not expected to change this situation while the 90% program will improve upon baseline conditions and result in positive impacts.

Plant Life. Component I relates to environmental concerns and primarily with native plants. Under baseline conditions, saltcedar has a negative impact on many native plants through displacement of entire habitats. The 50% program is expected to arrest saltcedar invasion and provide for moderate reestablishment of native plants, resulting in an improvement under existing conditions. The 90% program will greatly enhance the reestablishment of native plants and result in significantly positive impacts compared to baseline conditions.

Mexico. Component III deals with the economic base. Although little information is available, it has been observed that few large stands of saltcedar exist in Mexico and, under baseline conditions, the population is only moderately aware of the plant. No impacts are expected from either the 50 or 90% programs because saltcedar does not have a significant (positive or negative) role in the socio-economic structure of Mexico at the present time. This condition could change as the plant spreads over large areas and, then, similar impacts currently being experienced in the U.S. would also occur in Mexico.

#### D. Summary of Accounts

The results of the Economic Account indicate that both a 50% and 90% program would be effective in terms of benefits and costs. Total annual benefits are estimated to be \$22.0 million for the 50% program and from \$40.0 to \$60.0 million for the 90% program. Positive economic benefits occur in water use, livestock forage, flooding, and recreation; while negative economic benefits would accrue to sedimentation, dove hunting, honeybees, and ornamentals (Brown 1989).

Results for the Environmental Account indicate that existing saltcedar infestations, under baseline conditions, adversely affect water use, forage, flood protection, recreation, 1 mammal species, 2 bird species and 28 native and threatened plant species. Positive impacts occur in sedimentation, dove

populations, honeybees, soil stabilization and 2 bird species. A 50% control program would enhance flood protection, recreation, ornamentals, 1 mammal species, and 10 plant species. The 50% program would have no adverse impacts on any of the baseline categories. The 90% control program would enhance water use, forage, ornamentals, 12 bird species, and 17 plants species and would greatly enhance flood protection, recreation, 1 mammal species, 1 bird species, and 10 plant species. Adverse impacts would occur in sedimentation, dove populations, honeybees, soil stabilization, and 3 bird species. There would be no areas that incur significantly adverse impacts. In total, for the Environmental Account, the 10 agricultural-recreational factors had a small beneficial (+3-point) increase with biocontrol over baseline, the 36 wildlife species had a small to moderate (+2 to +12-point) increase, and the 42 plant species had a large (+36 to +53-point) increase (Table 74).

The Social Account indicates that, under baseline conditions, saltcedar adversely impacts water use, forage, flood protection, sedimentation, recreation, ornamental landscaping, wildlife and plant life. Positive impacts are found in dove hunting, honeybees, windbreaks, and soil stabilization.

A 50% level of control would result in positive socio-economic impacts in flood protection, sedimentation, recreation, wildlife, and plant life. Adverse impacts would occur in sedimentation and ornamental landscaping. There are no significant positive or adverse impacts estimated to occur in any of the categories. Baseline conditions for the remaining categories not listed above would not change under a 50% level of control.

The 90% control program would positively impact the socio-economic aspects of water use, forage, flood protection, recreation, ornamentals, and wildlife. Significant positive impacts would result in sedimentation, recreation, wildlife, and plant life. Adverse impacts would occur in

Table 74. Summary of environmental account of the projected effects of 50% or 90% effective biocontrol programs for saltcedar (summarized from Brown 1989, his Table 15.2).

Degree of control	Number of factors or species affected by each degree of impact of biocontrol <sup>a/</sup>														
	10 Agricultural-recreational factors					36 Wildlife species					42 Plant species				
	-2	-1	0	+1	+2	-2	-1	0	+1	+2	-2	-1	0	+1	+2
Baseline (none)	1	3	2	4	0	0	3	33	2	0	0	26	16	0	0
50% biocontrol	0	0	7	3	0	0	0	37	1	0	0	0	32	10	0
90% biocontrol	0	4	1	3	2	0	3	21	12	2	0	0	15	17	10

Net change <sup>b/</sup>  
in benefit:

50% biocontrol			+3					+2						+36	
90% biocontrol			+3					+12						+53	

<sup>a/</sup> Degree of impact: -2=very adverse; -1=adverse; 0=no impact; +1=beneficial; +2=very beneficial.

<sup>b/</sup> Net change: 1 point=1 factor or species change of 1 impact level (for example, from -2 to -1 or from +1 to +2); zeros not counted.

sedimentation, dove hunting, honeybees, and ornamentals. There would be no significant adverse impacts to any category. Finally, no impacts on baseline conditions are estimated to accrue to windbreaks and soil stabilization.

In total, for the social well-being account, a 50% effective control program would result in a net positive changed impact of +12 points and a 90% program would result in a net positive changed impact of +15 points over baseline (Table 75).

Brown (1989) concluded, based upon the results of the economic, environmental and social accounts, that the benefits of a biological control program for saltcedar are significantly greater than adverse impacts.

Table 75. Summary of social well-being account of the projected effects of 50% or 90% effective biocontrol programs for saltcedar (summarized from Brown 1989, his Table 15.3).

Type factor	Number of factors or species affected by each degree of impact of biocontrol (13 factors evaluated) <sup>a/</sup>																
	Baseline conditions (no control)					50% control					90% control						
	-2	-1	0	+1	+2	-2	-1	0	+1	+2	(net change)	-2	-1	0	+1	+2	(net change)
Individual	0	6	7	0	0	0	0	10	3	0	(+9)	0	0	7	3	3	(+12)
Community	0	2	10	1	0	0	0	12	1	0	(+2)	0	1	10	2	0	(+2)
Socio-economic	0	2	6	5	0	0	2	10	1	0	(-4)	0	4	7	2	0	(-5)
National emergency	1	1	11	0	0	0	0	12	1	0	(+3)	0	0	11	1	1	(+4)
Aggregate social	0	1	12	0	0	0	0	12	1	0	(+3)	0	0	12	1	0	(+2)
TOTAL	1	12	46	6	0	0	2	56	7	0	(+12)	0	5	47	9	4	(+15)

<sup>a/</sup> Degree of impact: -2=very adverse; -1=adverse; 0=no impact; +1=beneficial; +2=very beneficial.

<sup>b/</sup> Net change: 1 point=1 factor change of 1 impact level (for example, from -2 to -1 or from +1 to +2); zeros not counted.

## XX. SUMMARY

1. Taxonomy and Worldwide Distribution. Tamarix (Tamaricaceae) is a genus of ca. 54 species with its center of speciation in the Iran-Pakistan-southern USSR area and a secondary center in the eastern Mediterranean area. Ten species have been introduced into the U.S. as ornamentals, eight have become naturalized and two have become serious weeds, I. chinensis and I. ramosissima (these may be con-specific) and another, I. parviflora, is also weedy. A fourth species, athel (I. aphylla) is a widely, but not abundantly, used shade tree in semi-arid areas of the Southwest. The native range of I. ramosissima is from Turkey and Iran, through southern USSR and to China and Mongolia. The native range of I. chinensis is throughout China and to Korea and Japan.

2. Spread and Abundance of Saltcedar in the U.S. Saltcedar (I. chinensis and/or I. ramosissima) invaded many western riverine systems between the 1890's and the 1930's. It increased in abundance rapidly from the 1930's through the 1950's, by which time it had occupied most of the available and suitable habitat in its central area of North American distribution in Arizona, New Mexico and western Texas. Spread into more outlying areas (Utah, Wyoming, Montana, central and southern Texas, and northern Mexico) occurred later and is still continuing in several areas apparently at a rapid rate. Six species of the genus are naturalized in the southeastern U.S.

The only nationwide estimate of acreage infested was of 900,000 acres in 1960, with a projection for 1.3 million acres of riparian land infested by 1970. Since then, several river valleys have been measured much more precisely but no nationwide estimates have been made. Most of these measurements mapped and summed the acreage in various vegetation community-

structural types. These community-structural types contain varying amounts of saltcedar, so that the total amount cannot be determined. Remote sensing, whose technology for measuring saltcedar was developed as part of this project, has good potential for measuring the actual amount of saltcedar. Also, many thousands of acres have been cleared by Government agencies since 1960, but maintaining them requires a continuing effort.

3. Biology and Ecology. Saltcedar is a <sup>facultative</sup> phreatophytic shrub or small tree that grows in dense thickets to height of ca. 10 m in disturbed areas along western streams and lakeshores. <sup>(Robinson 1965, Horton)</sup> The small pink to white flowers occur in loose <sup>spikes</sup> racemes on the terminals of branches. Blooming occurs from mid-spring to fall. <sup>(Wilkinson 1966, Went and Zepher)</sup> Flowers are insect pollinated and attract a large number and variety of insects, including honeybees.

Seeds are small, wind-dispersed, and are produced in phenomenal numbers and germinate within 12 hrs after being wet. Ungerminated seed usually do not survive to the next year. Seedlings become established in dense stands on wet silt bars after floodwaters recede.

Foliage consists of scalelike leaves on photosynthetic cladophylls (cylindrical leaf-like branches). The foliage turns a golden-orange color in late fall before leaf fall, which varies from November to December at different latitudes. At this time, the foliage can be distinguished from other vegetation present by remote sensing.

The roots grow rapidly, up to 19 ft laterally in a 3-year-old plant. Primary roots extend deeply and branch laterally when they encounter a clay layer or at the water table and in the capillary zone above. Adventitious roots and new shoots form on stems covered with silt during flooding. Shoots are produced from a bud zone near the soil surface if the aerial part of the plant is killed, as by fire or herbicides.

Plants are very tolerant to inundation by floodwaters. . . . Most trees survived 71 days of root-crown submergence but were killed by 98-107 days submergence. After 81 days, mortality increased as more of the aerial part of the plant was submerged.

The leaves contain glands that excrete salt and enable the plant to grow in saline soils and with a saline ground water supply. Plants can grow with a soil water level of 10,000 ppm salt and grow at 50,000 ppm in some locations.

4. Displacement and Degradation of Native Plant Communities. The displacement of native plant communities, and the consequent degradation of habitat for most species of birds and mammals, is the most obvious, the most destructive, and the best documented effect of saltcedar invasion of western riparian ecosystems. The unique biology and ecology of saltcedar give it a great competitive advantage over most species of native vegetation in riparian ecosystems of western North America. These biological characteristics fit "hand in glove" with modifications made by man to greatly increase its advantage over native plants, as follows:

a.) Fire readily kills cottonwoods and several other native plants but kills only the above-ground parts of saltcedar, after which it rapidly resprouts; it may regrow to heights of 6-10 ft in the first year after burning. The heavy litter fall from the deciduous leaves of saltcedar greatly increases the incidence of fire. Saltcedar quickly gains dominance over many other species after fires.

b.) The reduction in flooding, and the shift in the seasonality of flooding downstream from dams and reservoirs built on many rivers for irrigation and flood control, gives saltcedar a strong competitive advantage over cottonwood and willow. Cottonwood blooms only in early spring and its seed

germinate on new sediment after spring floods; by the time the modified flood flows subside <sup>later</sup> in summer, seed production has ended and the seeds already produced are not longer viable. However, saltcedar blooms from spring into fall and its seed are abundantly present throughout that time. In addition, the seed of saltcedar germinate very quickly after becoming wet, enabling it to establish quickly after receding flood waters <sup>recede</sup>.

c.) Saltcedar is more tolerant of and survives inundation more readily than many native plant species.

d.) On "uncontrolled" rivers, the spring floods leach salts from the soil. On "controlled" rivers, the flooding is much less, allowing a salt accumulation that eventually exceeds the tolerance levels of some native plants in some areas. Saltcedar is more salt-tolerant than any native tree species in these areas and, thus, receives a strong competitive advantage. In addition, glands in the leaves of saltcedar secrete salt which drips to the ground or falls with the leaves, forming a layer of salt that inhibits germination and establishment of nearly all <sup>other</sup> plant species.

e.) Saltcedar has a specialized physiology that causes stomatal closure and results in transpiration rates considerably below potential during the hottest part of the day. This makes it more tolerant of heat and water stress than the native plants with which it competes.

f.) Most mechanical and herbicidal controls kill native vegetation more easily than they kill saltcedar, which resprouts to some extent after most treatments from buds on the main stem just below the soil line.

g.) Over-grazing by livestock often totally eliminates reproduction of cottonwoods and other riparian plant species; saltcedar is less palatable to most livestock than many species, again gaining a competitive advantage.

h.) Saltcedar apparently uses more water than many native species

(possibly twice as much as velvet mesquite) which increases the disastrous effects of declining water tables more than would be caused by other plants. As water tables decline, the deep root system of saltcedar enables it to survive when some native species cannot (although several native species also have deep root systems).

i.) Finally, no native insect herbivores feed sufficiently on saltcedar to cause it any significant stress or to slow its growth, reproduction and spread. However, one accidentally introduced insect from southwest Asia occurs in great numbers, causes considerable stress and is acting as a biocontrol agent. Without it, saltcedar would have an even greater advantage over native plants. Native plant species are more attacked by native natural enemies and incur some retardation in growth and reproduction.

Native riparian plant communities have been displaced on a large scale in the southwestern U.S., caused by a variety of factors related to human settlement and development (cutting for firewood, dams for irrigation, lowered water tables from pumping of groundwater, overgrazing by livestock, urbanization, fire, phreatophyte control programs, clearing for agricultural crops) but also caused by being out-competed by the invading saltcedar. In many river systems, saltcedar now constitutes half or more of the total vegetative cover and ~~is~~ <sup>is</sup> often the ~~only~~ <sup>nearly</sup> plant that occurs in large, pure stands. In dense stands, the very dense canopy cover and shade of saltcedar, plus the deposition of salt on the soil surface, eliminates nearly all other forbs, grasses or other smaller trees and shrubs.

5. Damage in Parks and Wildlife Areas. Saltcedar damages state and national parks and recreational areas by limiting access by visitors, increasing insect problems, allergies and dust, causing boating hazards, and by seriously compromising the National Park Service's mission (and that of

several conservation organizations) to maintain areas in their natural condition. An economic analysis indicated that benefits in increased usage of parks would value \$0.7 million annually from a 50% effective biocontrol program for saltcedar and from \$2.3 to \$7.0 million annually for a 90% effective control program. Most of the western National Parks and National Monuments are infested with saltcedar to varying degrees along rivers, intermittent streams and springs. In many cases, drinking water sources <sup>for wildlife</sup> have dried up or have been reduced. Control is mostly limited to hand cutting and stump treatments (a very labor intensive and expensive method used in order to conserve the other vegetation) and several retreatments are required. In some cases, springs and ponds have reappeared and wildlife has returned after saltcedar and athel were removed.

6. Revegetation. Once saltcedar is removed or reduced in density in an area, the natural vegetation and wildlife habitat can re-establish naturally if the physical characteristics (soil and water salinity, water-table depth) are suitable. If revegetation does not occur naturally, trees and shrubs can be planted. In some areas, riparian land has been purchased for the preservation and improvement of wildlife habitat. Different revegetation techniques are required in different areas, depending primarily on depth to the water table and soil and soil-water salinity. In the Lower Rio Grande Valley of Texas, revegetation is easy and has been very successful.

Along the Middle Rio Grande and the Lower Colorado Rivers, pole plantings of cottonwood and willow and container plantings of honey mesquite, paloverde and quailbush have been attempted. Survival has been good if conditions are correct. Critical factors to survival are to insert poles in holes augered to the water table, irrigate container plants for 150 days, plant only where the water table is less than 15 ft and salt content is less than 1200 ppm,

add that mesquite  
at 70000 successful

add causes of failure  
by arbores

prevent competition from weeds, and protect plantings from insect attack and grazing by livestock and wildlife. On the Lower Colorado, costs of revegetation varied from \$1,454 to \$10,464 per acre, with a most typical cost of \$3,700 per acre. Costs on the Middle Rio Grande were \$600-1,500 per acre and on the Lower Rio Grande of Texas were only \$165 per acre.

7. Effects of Saltcedar on Wildlife. The serious degradation of habitat quality caused by saltcedar invasion has been carefully documented for many species of wildlife. Species diversity (~~which is~~ one of the most important measures of ecological health) is substantially and significantly lower in saltcedar stands than in almost every other community type present. Densities of most species of wildlife also are lower in saltcedar than in native plant communities, although some species tolerate it well or even seem to favor it. However, most species that have high densities in saltcedar (especially certain songbirds) are edge dwellers; they use the saltcedar only for cover and they feed in nearby areas of annual weeds or agricultural areas. They probably could thrive equally well in any vegetation of a similar structural type if it replaced saltcedar.

Saltcedar itself provides little food for wildlife. The foliage is largely unpalatable, no fruit is produced, the seed are not eaten, few species of insects are produced on which birds could feed, and mistletoe (of great value to fruit-feeding birds and to deer) does not grow on it. However, some birds feed on the abundant pollen and the nectar feeding insects that are attracted to the flowers. Some probably feed on the introduced cicadellid Opsius stactogalus that is often abundant. Some birds and rodents feed on the native Apache cicada that briefly reaches high populations in saltcedar in midsummer, whose nymphs feed on roots of saltcedar and other

plants. Some mammals feed to a limited extent on the foliage of young saltcedar plants or sprouts.

a.) Non-game birds.

1.) On the Lower Colorado River, CA and AZ, the density and species richness of non-game birds was lower in saltcedar than in most other community types. The average density of all bird species in saltcedar was only 59% as great as the average of the cottonwood-willow, screwbean mesquite, and velvet mesquite communities during the year, and only 39% as great during the more critical winter months. Only 75% as many bird species occurred in saltcedar as in the average of the other communities. No avian group increased as saltcedar increased, but 4 of the 9 groups decreased as saltcedar increased. Of 8 community types, saltcedar ranked 5th in number of bird species, 3rd in bird species diversity, and 7th in community diversity. Several bird species are in danger of extirpation because of the loss of cottonwood-willow habitat.

2.) On the Rio Grande of western Texas during the summer, 8 bird species preferred and 3 strongly preferred cottonwood-willow while 3 preferred and none strongly preferred saltcedar; during the winter, 15 species preferred and 12 strongly preferred cottonwood-willow and only 2 preferred and none strongly preferred saltcedar. However, further upstream in New Mexico, 4 common resident bird species rarely occurred except in saltcedar.

3.) On the Middle Pecos River, 93% of the original vegetation is now in saltcedar, mostly in young, short plants of less value to birds than larger trees. In overall value to birds, saltcedar IV ranked 3rd and SC-V ranked only 5th among 14 community-structural types. Strangely, in bird density the taller SC-III ranked 5th in early summer, 7th in fall, 8th

in spring, 10th in late summer, and 11th in winter; in bird-species diversity it ranked 6th in early summer, 8th in late summer, and 11th to 13th in other seasons.

4.) Birds appear to use saltcedar more as one progresses eastward from the Colorado River, AZ-CA to the Rio Grande, and to the Pecos River, NM, and toward higher elevations and less intensely hot summers. However, the more eastern rivers also contain a greater diversity of plants in the areas labeled "saltcedar" (sometimes with more cottonwood, mesquite and baccharis than saltcedar) and contain more annual plants than the rivers to the west. The most reasonable conclusion is that the birds use the "saltcedar" more because these areas contain more plants of other species than in the Lower Colorado. Another factor could be that saltcedar might not mitigate the effects of high temperatures as well as would other community types.

b. Non-consumptive usage.--Expenditures for non-consumptive use of wildlife (observing, photographing, feeding) is \$14 billion in the U.S., or 60% more than for all types of hunting combined. The effects of saltcedar on this usage was calculated by two methods. In the first, this usage in Arizona was valued at \$246.6 million and in New Mexico at \$131.9 million annually. The value of the proportion of this that could take place in riparian areas occupied by saltcedar was calculated to be \$89 million in Arizona and \$47.6 million in New Mexico. Assuming that a loss of 33% in value to birds is caused by saltcedar (the average of several large-scale surveys), loss caused by saltcedar was estimated at \$30 million in Arizona and \$15 million in New Mexico annually. If the time of the primary non-resident adult participants (440,000 in Arizona and 189,000 in New Mexico) were included, these values would double. The number of non-consumptive participants is ca. 10 times the number of dove hunters in these states. By

the second method, the value of "bird watching" in Arizona was calculated to be \$59 million annually. The proportion allocated to saltcedar infested areas was thought to be too uncertain for calculation and losses caused by saltcedar could range from insignificant to several million dollars annually.

c. Game birds: white-winged dove.--With game birds and mammals, saltcedar is heavily used by the white-winged dove, and to a somewhat lesser extent by the mourning dove, but not by any other species; for most species, it is poorer habitat than the native vegetation. The white-winged dove breeds in the southern one-third of Arizona, barely into the southwestern corner of New Mexico, along the Rio Grande of western Texas north to Alpine, and across southern Texas from Del Rio and San Antonio southward. It overwinters in Mexico and Central America.

Accounts by the early travelers to the Southwest, before farming began, indicate that whitewings were common but not abundant. The northern limit of the whitewing has moved northward in Arizona, into the Trans-Pecos area of Texas, and into the inland areas of south Texas since that time and the huge nesting colonies, both in Arizona and south Texas, apparently developed after grain farming began.

Today, the largest populations, ca. 19 million whitewings, breed in northeastern Mexico, mostly in Tamaulipas. This zone extends into the Lower Rio Grande Valley of Texas, where populations of ca. 1 million whitewings breed. Other populations of 25,000-30,000 whitewings breed at several scattered, more inland areas of southern Texas and along the Rio Grande of western Texas. Populations in three more northern areas, for example, the Trans-Pecos and San Antonio city, appear to have increased substantially from 1988 to 1990. Another perhaps 1 million whitewings breed in Arizona, with smaller numbers in Sonora and northern Sinaloa. In some areas where

suitable nesting trees, water and food are available, whitewings nest in huge colonies. In Arizona, whitewings in the large nesting colonies are almost totally dependent on cultivated grains for food. From these colonies, the doves fly out in large numbers to certain grain fields at fixed times each day to feed.

In south Texas and Tamaulipas, the preferred nest trees are the native Texas ebony, anacua, huisache, colima, granjeno, and Brasil. The doves only rarely nest in honey mesquite and saltcedar does not occur here, although some athel trees grow here. Since the early 1900's, over 95% of the native habitat has been cleared for irrigated agriculture. Doves gradually nested more in citrus trees as this acreage increased, with from one-third to two-thirds of the population nesting there, depending on the condition of the trees. Periodic freezes each 5-15 years kill a large part of the citrus, which causes a crash in the dove population and a closing of the hunting season for 1-3 years until populations begin recovering. Populations are also somewhat depressed, especially in the colonies, by predation by grackles and green jays.

In Arizona, the majority of the total population inhabits desert areas in very disperse populations, nests in trees in desert washes and in saguaro cactus, and obtains water from the few streams, springs or livestock watering tanks, which they visit from as far away as 10 miles. The preferred nesting habitat of the colonies for many years was dense thickets of velvet mesquite along the Gila, Santa Cruz, Salt, and other rivers. However, by the 1960's saltcedar had replaced much of this vegetation; and by the 1970's, the more famous thickets had died because of falling water tables from pumping groundwater and because of wood cutting. More recently, the doves nest almost entirely in saltcedar, although in some riparian areas, they still occur more

in other vegetation than in saltcedar. Harvest records in Arizona have fallen drastically from a peak of 600,000 to 700,000/yr and an average kill of 5-6 doves per hunter per trip in the 1960's to 100,000 to 200,000 and an average kill of 1.0 to 1.4 per hunter per trip in the 1980's. This decline was caused in part by the death of the mesquite thickets (though saltcedar thickets are still plentiful), partly to overhunting, but probably mostly (since the nesting habitat is presently underused) to a shift in agriculture from grain to cotton, resulting in a serious limitation on the food supply. The decline in populations has also greatly reduced the number of persons who hunt.

The white-winged dove is extremely popular with hunters because of its fixed behavioral patterns of feeding in certain grain fields day after day and of flying from the nesting colonies to these fields at a predictable time each day. The hunters don't actually need to "hunt," they only need to drive to the known fields at the appointed time and wait for the doves to arrive by the thousands. The doves are usually shot as they fly into the feeding fields or while they are feeding. The hunting season is usually for only ca. 4 days at the first of September, after the young are able to care for themselves and before the migration to the wintering areas begins. Limits are 10-15 doves per day, depending on populations.

The major hunting areas are in the Lower Rio Grande Valley of Texas and along certain riparian areas of Arizona where thickets of mesquite or saltcedar occur and in Tamaulipas. Lesser amounts of hunting occur where populations of ca. 30,000 birds occur at each of the several scattered more inland areas of south Texas, in the similar area of Trans-Pecos Texas, and in Sonora and Sinaloa. In Texas, since 1976, an average of ca. 358,000 whitewings have been harvested annually during an average 88,600 hunter-days.

In Arizona, since 1981, an average of ca. 147,000 whitewings have been harvested annually by 33,000 hunters.

In Trans-Pecos Texas, total whitewing populations are estimated at ca. 200,000 but hunting there appears to be minor compared with the other areas. Dove hunting in south Texas adds ca. \$2 million annually to the local economy. Similar estimates for Arizona were not obtained.

The more wealthy hunters go to Tamaulipas where limits are higher and where they can shoot two or three times the limit without being apprehended. A small amount of hunting also occurs in Sonora and northern Sinaloa. Nearly all the hunting in Mexico is by hunters from the U.S. The average hunting trip to Mexico cost \$400 in 1980, with another \$350 spent in south Texas before and after the hunt.

In south Texas, 7,400 acres has been purchased by various agencies since the 1960's, part of it for white-winged dove habitat. The Texas parks and Wildlife Department has an active program there to revegetate the acquired lands with native trees and to contract with local owners for other habitat improvements, paid for with the white-winged dove stamps that it sells. The Texas Parks and Wildlife Department in 1985 purchased 2,000 acres in the Trans-Pecos area, 400 acres of it saltcedar bottomland, for white-winged dove habitat. The area is somewhat remote to most hunters and dove populations may also be limited by a lack of grain farming in the area. Revegetation of the riparian areas, especially in Arizona, could restore the natural habitat and planting grain could restore the food supply. Both of these alternatives, especially revegetation of a sufficiently large area, would be costly. Also, any revegetation efforts will fail if the water table is too low. Land acquisition in Arizona probably would need to be accompanied by the acquisition of water rights.

Whitewing populations in the Lower Rio Grande Valley, upper south Texas and the enormous populations in Tamaulipas (probably 90% of the U.S.-Mexican population of the species) are unaffected by saltcedar because the plant does not grow there. In Arizona, the dispersed populations in the desert, that make up the bulk of the total population, apparently are maintaining a more or less constant population. However, populations of the huge nesting colonies so favored by hunters are in serious decline. These populations presently are heavily dependent for nesting on stands of large, mature saltcedar because the original preferred velvet mesquite thickets are mostly gone. However, the immediate limiting factor appears to be a shortage of food since many farmers switched from grain to cotton several years ago; the available saltcedar thickets are presently under-utilized. The most pressing long-term problem is declining water tables that will eventually cause the death even of the saltcedar thickets as has already happened along the Salt River near Phoenix.

d.) Game birds: mourning dove.--The mourning dove breeds throughout the contiguous states of the U.S. and Mexico and overwinters from the southern half of the U.S. to Mexico. It is much more generalized in habitat requirements than the white-winged dove. It inhabits wood edges, shelterbelts, cities, farmlands, and orchards; and in the plains states it frequently nests on the ground. In Arizona, it nests in more mixed habitats such as orchards, screwbean mesquite, cottonwood-willow, honey mesquite, and saltcedar, while the white-winged dove nests mostly in saltcedar in riparian areas. The clearing of phreatophyte areas in the Southwest probably has harmed the mourning dove, though it is little associated with a particular plant species. However, populations overall have remained relatively stable over the years. Mourning doves feed mostly on seeds of various native

plants, such as Croton, caltrop and rockcress; they feed on cultivated grains but are not dependent on them.

In the Southwest, mourning dove hunting is of much more importance than whitewing hunting (13 times as great in Arizona). The mourning dove would probably be but little affected by any biological control of saltcedar; its populations might actually increase if the present dense saltcedar stands become more open and contained a greater diversity of tree species, especially if screbean and honey mesquite increased. If, however, arrowweed, saltbush or other low-growing species replaced saltcedar, mourning dove densities would likely decline. In some areas at least, mourning dove populations could respond more than could whitewings to nesting habitat improvement because it is not dependent on agricultural grains.

e.) Gamebirds: Gambel's quail.--Gambel's quail is another major game bird in the Southwest. In Arizona, the annual harvest from 1981-87 averaged 1,158,095 birds annually, which was 73% that of the mourning dove and 7.2 times that of the white-winged dove. An average 74,800 hunters averaged 2.3 birds bagged per trip. On the Lower Colorado, populations were highest in velvet mesquite and lowest in cottonwood and saltcedar in all seasons; they preferred patchy stands of vegetation with saltbush and annuals present. On the Rio Grande of western Texas, 32 to 38% of the population inhabited screwbean mesquite or thorny shrubs and only 5% inhabited saltcedar. They fed mostly on seeds of cultivated grains, screwbean mesquite, mistletoe, and other seeds.

f.) Terrestrial vertebrates.--Terrestrial vertebrates seem to be affected in a manner similar to birds.

1.) Rodent species varied in response to saltcedar. On the Lower Colorado, the cactus mouse and deer mouse preferred saltcedar, and most

other species preferred ~~screwbean or velvet mesquite~~. On the Rio Grande of western Texas, saltcedar ranked 5th in number of species and 6th in density among 7 vegetation types. On the Middle Rio Grande, NM, saltcedar-IV ranked 9th, SC-VI ranked 15th and SC-V ranked 16th among 25 community-structural types; cottonwood-willow ranked first.

2.) Most reptiles and amphibians also do not prefer saltcedar. On the Colorado River in the Grand Canyon, open saltcedar ranked 3rd and dense saltcedar ranked 9th out of 10 habitat types in number of reptiles trapped. On the Rio Grande of western Texas, very few were trapped in saltcedar. On the Middle Rio Grande, one saltcedar transect equaled cottonwood-willow but the other two saltcedar transects ranked low in numbers of lizards caught.

g.) Other game animals and birds.--In the Southwest, several species of game animals are dependent on riparian areas, most other animals are facultative users and most trapping of furbearers occurs there. On the Rio Grande of western Texas, on an equal-area basis, 51% of all animals surveyed were in cottonwood willow, 29% in thorny shrub, and only 9% in saltcedar. On the Pecos River, NM, 36% were in cottonwood-willow, 21% in saltcedar and lesser numbers in other habitats.

h.) Impacts of biological control. Biological control of saltcedar is expected to have a beneficial effect on most species of wildlife, except for the white-winged dove, by increasing drinking water sources and by allowing the native cottonwood-willow, screwbean mesquite, honey mesquite, and other species to replace the majority of the saltcedar; these native plants provide better food sources, shelter, and nesting habitat than saltcedar. In Texas, only 5.5% but in Arizona 56.0% of all white-winged doves harvested are in saltcedar. An economic analysis estimated that a 50%

biocontrol program of saltcedar would adversely affect white-winged dove hunting by reducing the amount spent by hunters (which is directly related to hunter participation) by \$200,000 annually in Texas and by \$500,000 in Arizona. A 90% biocontrol program would reduce expenditures by \$300,000 in Texas and by \$1,100,000 in Arizona.

Mourning dove hunting would be little affected because of this dove's ability to adapt to other habitats. Hunting of the Gambel's quail and nearly all other game species would be improved because they are negatively affected by saltcedar. Non-game bird and mammal species would be little affected by a 50% control program but 90% control would benefit most species. Endangered species would be little affected by a 50% control except that the peninsular bighorn sheep would benefit (its drinking water sources have been dried up by saltcedar). A 90% control program would benefit 13 species of birds and harm 3 species of 35 species considered.

8. Use of Water by Saltcedar. Despite enormous effort by highly competent engineers and large-scale experiments over periods of several years, the measurement of water usage by saltcedar or possible replacement vegetation under natural conditions is not very closely defined. One problem is that no standard is available and it is not known which of the many methods attempted most closely measures usage under natural conditions. The accepted practice seems to be to use the average of several methods.

Measurements in lysimeter tanks have been done very carefully with techniques that improved greatly over the years and under conditions that appeared close to natural. These measurements sometimes were assumed to be the standard by which to calibrate other more indirect methods. However, later workers have pointed out numerous problems with these measurements, especially if the attempt is made to extrapolate the results on an area-wide basis.

In the 1970's, the development of new equipment allowed the use of micro-meteorological methods capable of measuring very small differences very frequently and with automatic computer processing of the data. These measurements appeared to give reasonable-appearing results. Still, there was no known standard of comparison and calibration in the field, although these methods have been used widely and are widely accepted in croplands.

Although the measurements vary with the method used, with depth to water table, salinity of ground water, density and age of the plants, temperature, wind velocity and possibly elevation of the site, the consensus of the available data indicates that saltcedar would use between 3 and 6 ft of water per year under natural conditions at different locations.

The best estimates of water usage by saltcedar probably are a maximum of 5.7 ft/yr (including 0.3 ft rainfall) near sea level on the Colorado River floodplain near Blythe, CA; 5 to 6 ft/yr at the higher elevations on the Gila River near Buckeye and Safford, AZ; and 3.2 ft/yr at the still higher elevation (4728 ft) on the Rio Grande at Bernardo, NM, and probably about the same on the Pecos River near Carlsbad, NM.

Horton and Campbell (1974) and Horton (1976) concluded from their review of previous work in lysimeter tanks that usage would be 6 to 7 ft at Buckeye, 5 to 6 ft at Safford and slightly less at Carlsbad, and 4 to 4.5 ft at Bernardo. Studies since then by T. E. A. van Hylckama and by Lloyd Gay and his coworkers using energy budget methods indicate that several of the lysimeter tank estimates may be too high. The measurement in tanks of 7.8 to 10.2 ft/yr by van Hylckama at Buckeye using "fresh" water at a water table of 9 to 5 ft appears too high in relation to other measurements. A more reasonable estimate of 5.6 ft was obtained in a 20 ft tank using natural groundwater at a salinity of EC 7.6. Likewise, the 7.2 ft estimate at

Safford (Gatewood et al. 1950) also seems too high, although had they used their raw estimate rather than extrapolating to 100% volume-density of vegetation, this estimate would have been a more reasonable 5.5 ft/year.

The experiments on lysimeter tanks at Bernardo to rapidly change the water table indicate that channeling of rivers to lower the water table in nature would not be an effective control for saltcedar. Within 1 or 2 years, the saltcedar roots would reach the lower water table and the plant would resume growth and water use. Likewise, cutting, thinning and burning produce only temporary, one-year reductions in water usage. If a caliche or clay lens were present between the saltcedar root zone and the lowered water table, saltcedar roots might not be able to reach the ground-water aquifer, and some control of saltcedar might be possible.

Great effort was made to measure water usage before and after clearing phreatophytes on a 15-mile reach of the Gila River by the "inflow-outflow" method, where water use by phreatophytes is the difference between all water entering the reach and all water leaving the reach, plus any change in storage. This is a direct measure that needs no extrapolation by questionable calculations. However, the total inflow and outflow is so large that small measurement errors mask the relatively small amount used by the vegetation.

Two experiments have been conducted to compare water usage before and after controlling saltcedar. The study on the Gila River, AZ (Culler et al. 1982) estimated a salvage downstream of 19.9 inches per year; however, this was before replacement vegetation became established, which they estimated would use all or nearly all of the water salvaged. In the most recent study on the Pecos River, NM, Weeks et al. (1987) compared usage in the field by saltcedar and replacement vegetation using the energy-budget and the eddy-correlation methods and using the most sophisticated modern equipment.

However, they were unable to close the energy-budget and were able only to set maximum and minimum usage rates. They estimated a salvage of from 7.9 to 15.7 inches/yr from the 21,500 acres of floodplain cleared of saltcedar.

Although the great impetus for most of the past research was to "salvage" water "off-site" for downstream agricultural, municipal or industrial use, the data indicate that probably little or no water can be saved downstream. Replacement vegetation would use most of the amount saved, and if vegetation does not become reestablished, severe erosion would occur and wildlife populations would be devastated. However, the possibility still remains that the intuitive judgment of the early workers may be true--that removing a species like saltcedar that uses a lot of water and replacing it with a species that uses less water will increase groundwater levels and stream-flow. It may be that the procedures for measurement in the field are so complex and so difficult that the quantities saved, although substantial, cannot be detected.

However, it would appear that all, or nearly all, of the water presently used by saltcedar would be available for use "on-site" by phreatophytic agricultural plants (alfalfa, bermudagrass or other) or by phreatophytic plants of much greater value to wildlife and recreational uses (such as cottonwood, willow, screwbean mesquite, honey mesquite, saltbush, quailbush, or other plants) than is saltcedar. The value of the water saved from saltcedar usage would be equal to the increased value of these plants.

9. Sedimentation, Flooding and Salinity. Along streams where flooding occurs, a dense growth of saltcedar slows the floodflow causing deposition of silt, narrowing of the channel and eventually complete blockage of the channel with debris or loss of channel identity with the water being dispersed into many small meandering streams. This causes an increased

height of the flood crest and increased damage when large floods occur. Such cases have been documented on the Gila, the Pecos and the Brazos Rivers. The beneficial value of biocontrol for flood reduction was estimated at \$23 million annually for 50% control of saltcedar and \$39.8 million annually for 90% control.

Saltcedar growing above reservoirs causes sedimentation with the consequent harmful effects of altering the native plant and animal communities, increased flooding, blockage of channels, etc. However, this has a positive effect of preventing sedimentation from reaching the reservoir itself and shortening its useful life or requiring dredging to remove it. Biological control of saltcedar would, therefore, have positive benefits above the reservoir but negative effects of increased sedimentation of the reservoir itself. However, an economic analysis showed that the negative effects of biocontrol on the Lower Colorado, Rio Grande and Pecos Rivers are minor (\$500,000 annually for 50% saltcedar control and \$1,000,000 annually for 90% control).

Saltcedar can grow in more highly saline soils and with more saline groundwater than can most other plants. In addition, the action of saltcedar increases soil salinity still more by the dripping of brine from the leaves to the soil surface and the shedding of the leaves in the fall. This creates a soil surface so highly saline that virtually nothing else will grow until the salt is leached by flooding or rains.

10. Livestock Forage. Saltcedar reduces biomass of grasses and other livestock forage plants in proportion to the canopy cover of the saltcedar. Dense saltcedar stands contain essentially no forage plants. However, cattle will graze saltcedar sprouts after mowing or fire to a substantial degree while they are young. In one test, cattle ate ca. half of the

saltcedar biomass produced after mowing. Periodic mowing was required to keep the sprouts from growing higher than the cattle could reach. No information was found on the nutritional value of saltcedar.

11. Value for Ornamental and Shade Trees. Saltcedar is occasionally used as a shade or ornamental tree in yards. In Arizona, parts of southeastern California, and small parts of southern Nevada, southwestern Utah, and the western half of New Mexico, the value of ornamental saltcedar was estimated at \$13.4 million (0.24% of all shade trees) and athel at \$15.9 million (0.28% of all shade trees). In Texas, the value of saltcedar was estimated at \$20.7 million and of athel at \$30.3 million. In Texas, saltcedar and athel were not identified separately in the surveys, and this is based on a rough estimate of the proportion of each present. The eastern half of New Mexico was not included, but this area has only small towns and the value not included is small. Total one-time value of saltcedar used as ornamentals is, then, ca. \$34 million. In a different analysis, using replacement values and costs spread over a 10-year period, a 50% effective biocontrol program caused an annual loss of \$698,000 in the southwest and a 90% effective program caused losses of \$1,256,000 annually. After 10 years no more damage would be incurred and the replacement trees would be more valuable than the saltcedar trees they replaced.

12. Value for Honeybees. Saltcedar is of some value to beekeepers in Arizona, New Mexico and possibly Trans-Pecos Texas. Some beekeepers reported it to be the most important plant for them for both honey and pollen production. However, on the average, saltcedar ranked only 7th for honey production and 4th for colony maintenance in Arizona; insufficient data were obtained from New Mexico and Texas to estimate its rank. The value of honey only that might be lost by complete biocontrol of saltcedar was calculated

by one method to be \$190,000 annually for Arizona and New Mexico. By another method, 90% saltcedar control would reduce the value of all bee products by \$1.48 million annually in Arizona, New Mexico and Texas. In a 50% effective control program, no losses were projected. If saltcedar were replaced after biocontrol by cottonwood, willow, mesquite, and seepwillow baccharis, then these losses could be minimal or none. The degree of control likely to be attained with biocontrol methods will leave a substantial portion of the needs of beekeepers in place.

13. Windbreaks and Soil Stabilization. Saltcedar is only rarely used as windbreaks, probably because of its deciduous nature. It is sometimes planted around oil wells for soil stabilization. The evergreen athel is the species most used for windbreaks in the southwest because it is evergreen.

14. Other Beneficial Values. Saltcedar is used to a very minor extent in Mexico for firewood, fenceposts, etc. Most of this usage is of athel.

15. Natural Enemies of Saltcedar. In the United States, 145 species of native insect herbivores have been collected from saltcedar but none of these cause significant damage to the plant. One insect, the accidentally introduced leafhopper, Opsius stactogalus, which probably is specific to saltcedar, reaches high populations and causes considerable damage, but to date, it has caused no reduction in stands of saltcedar. Many insects have been reported attacking saltcedar within its native range in Israel, Turkey, Italy, southern USSR, and Pakistan. Preliminary exploration and testing has identified at least 9 species of insects in Israel and 10 additional species in Pakistan that are promising candidates for introduction; these species appear not to attack athel there. Among these natural enemies are gall forming insects and mites that attack stems or buds, moths and beetles that feed on foliage or that bore in the stems, and bugs and scale insects that

suck sap from the leaves and stems. Additional candidates probably could be found with further exploration, especially in China and southern USSR.

16. Non-biological Control of Saltcedar. Most chemical and mechanical controls employed to date have been ineffective in controlling saltcedar unless periodic maintenance applications are used, from monthly to each 3-5 years, depending on the method used. In addition, all these controls also kill much or all of the other vegetation present, necessitating costly revegetation operations or else long periods for other vegetation to reestablish naturally, during which time the saltcedar also reestablishes.

Mechanical controls alone, such as mowing, chaining, bulldozing and root plowing, allow the rapid regrowth of saltcedar, whose sprouts often grow 6-8 ft the first year after treatment. The chemical silvex is now banned from usage. Triclopyr is an effective stump treatment but is extremely labor intensive and requires 1 to 3 or more retreatments for effective control. The new imazapyr gives good control but also kills most other vegetation except legumes. Combinations of chemical and mechanical controls are most effective but cost \$55 to \$77 per acre per year over a 20-year control program.

Fire not only fails to kill the root-crowns of saltcedar (which quickly regrow) but kills much of the native vegetation (especially cottonwoods), giving saltcedar a strong competitive advantage. Inundation can kill saltcedar if the trees are completely submerged for ca 100 days; this method can be applied only in limited areas above reservoirs and also kills the other vegetation.

17. Biological Control. Saltcedar is almost ideally suited to biological control by the introduction of natural enemies from its area of natural distribution in Asia. Saltcedar is a perennial plant in a stable

ecosystem, it causes great damage--in locations where other methods are too destructive to the native vegetation, it is not closely related to any native North American plants, several promising natural enemies are already known, and the infrastructure for the needed overseas explorations and testing is already in place. Introduced foreign control agents would exert a constant and continuing suppressing action that is needed to counteract the constant and continuing competitive advantage saltcedar now enjoys over other vegetation. Biological control would not damage other plants, as do all chemical and mechanical controls, and would allow the increase of native vegetation as saltcedar decreased.

An analysis of 25 common native riparian plant species indicated that all would benefit from biocontrol of saltcedar; an analysis of 16 rare species indicated that 1 would benefit and none would be harmed. Biological control is expected to kill saltcedar plants gradually over a period of several years at any given location, the type of damage depending on the type of control agent used (foliage, flower, stem feeder, etc.). The original native vegetation is expected to gradually increase in the spaces created between the saltcedar plants and to the degree to which saltcedar is controlled. However, some uncertainty exists regarding the replacement vegetation, and some biologists suggest that arrowweed and other plants of low wildlife value might replace saltcedar in large areas. We regard this as unlikely unless the area has been physically changed to a swampy condition favorable to arrowweed. Another problem is that the water table has fallen in some areas through pumping for agriculture and municipalities (and by consumptive used by saltcedar) and that soil salinity has increased (caused in part by saltcedar) to the point where establishment of replacement vegetation may be difficult.

Conflicts of interest need to be resolved between its harmful values (to native plant communities, degradation of habitat for most wildlife species and excessive water usage) and its beneficial values (for white-winged dove nesting habitat, as a pollen and nectar source for honeybees, and its use for landscaping trees) before biological control begins.

Biological control should allow the native vegetation to replace saltcedar in most areas, with a smaller amount of saltcedar remaining as a permanent part of the plant community. This has been the situation in all previous successful biological control projects in the U.S. and many other countries.

18. Economic Effects of Biocontrol of Saltcedar. An economic analysis was performed of the harmful, beneficial and ecological effects of saltcedar and the projected economic, environmental and social effects of a 50% or a 90% biological control program. This analysis was performed by Great Western Research, Mesa, AZ, under separate contract with the Bureau of Reclamation. A summary of each part of this analysis is presented with each of the pertinent sections of the present report. The analysis displayed values separately in economic, environmental and social accounts.

In the economic account, biological control was beneficial to conserving groundwater, for livestock forage, flood prevention and recreation whereas it was detrimental by causing increased sedimentation of reservoirs and to dove hunting, the honeybee industry and ornamentals. Overall net annual benefits were \$22 million with a 50% program and \$40 to \$62 million with a 90% control program.

The environmental account examined 10 agricultural-recreational-wildlife factors, 36 species of wildlife and 42 plant species. The effects produced on each factor or species by saltcedar was rated as -2 (very adverse), -1

(adverse), 0 (no impact), +1 (beneficial) or +2 (very beneficial), all under present baseline conditions or projected effects with 50% or 90% biocontrol of saltcedar. The 10 agricultural-recreational-wildlife factors had a total beneficial increase of +3 points over baseline with both a 50% and 90% program. The 36 wildlife species had a +2-point beneficial increase with a 50% program and a +12-point increase with a 90% program. The 42 plant species had a +36-point increase with a 50% program and a +53-point increase with a 90% control program.

The social well-being account evaluated 13 factors as they affected the individual, community, socio-economic, national emergency, and aggregate social sectors, using the same scale from -2 to +2. A 50% control predicted a total beneficial increase of +12 points and a 90% program, an increase of +15 points.

# ~~XXI. LITERATURE CITED~~

- AZG&FD. 1988. Arizona game survey and harvest data summary. Ariz. Game and Fish Commis., Fed. Aid Proj. W-53-R-38. 146 pp.
- Airy-Shaw, H. K. 1973. A Dictionary of the Flowering Plants and Ferns. 8th ed., revision of J. C. Willis. Cambridge Univ. Press. 1310 pp.
- Aitchison, S. W. 1977. Some effects of a campground on breeding birds in Arizona. pp. 175-182. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Ft. Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Akashi, Y. 1988. Riparian vegetation dynamics along the Bighorn River, Wyoming. M.S. Thesis. Univ. Wyoming, Laramie. 245 pp.
- Almand, J. D. and Krohn, W. B. 1978. Position paper: The position of the Bureau of Land Management on the protection and management of riparian ecosystems. pp. 359-361. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of flood-plain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Ames, C. R. 1977. Wildlife conflicts in riparian management: Grazing. pp. 49-51. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Anderson, B. W. 1986. Revegetation of a 25-acre plot on the Kern River Preserve. Colorado River Lab., Blythe, CA. Nature Conservancy and Calif. Dept. Fish and Game, San Francisco and Sacramento. 58 p.
- Anderson, B. W. 1987. Evaluation of growth of trees on Kern River Preserve dump revegetation site during 1987; Appendix to 1986 Final Report Concerning Revegetation on the Kern River Preserve. Revegetation and Wildlife Manage. Cen., Blythe, CA. Nature Conservancy and Calif. Dept. Fish and Game, San Francisco and Sacramento. 17 p. + app.
- Anderson, B. W. 1988a. Soil and salinity conditions in the Lower Colorado floodplain. Revegetation and Wildlife Manage. Cen., Inc., Blythe, CA. Nature Conservancy and Calif. Dept. Fish and Game, San Francisco and Sacramento. 34 p. + app. ★
- Anderson, B. W. 1988b. Evaluation of tree growth on the Kern River Preserve dump revegetation site after three seasons. Revegetation and Wildlife Manage. Cen., Inc., Blythe, CA. Nature Conservancy and Calif. Dept. Fish and Game, San Francisco and Sacramento. 25 p. + app. ★

Anderson, B. W. 1988c. Revegetation of two 25-acre plots on the Kern River Preserve. Revegetation and Wildlife Manage. Cen., Blythe, CA. Nature Conservancy and Calif. Dept. Fish and Game, San Francisco and Sacramento. 42 p. + app.

✓ Anderson, B. W. and Ohmart, R. D. 1977a. Vegetation structure and bird use in the Lower Colorado River Valley. pp. 23-34. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

Anderson, B. W. and Ohmart, R. D. 1977b. Wildlife use and densities report of birds and mammals in the Lower Colorado River Valley. Annual report 1977. Bur. Reclam., Lower Colorado Reg., Contract No. 7-07-30-V0009. 355 pp.

Anderson, B. W. and Ohmart, R. D. 1979. Riparian revegetation: an approach to mitigating for a disappearing habitat in the Southwest pp. 481-487. In: Swanson, G. A. (Tech. coord.), The mitigation symposium: A national workshop on mitigating losses of fish and wildlife habitats, July 16-20, 1979, Fort Collins, CO. USDA For. Serv., Rocky Mtn. For. Range Expt. Sta., Ft. Collins, CO. Gen. Tech. Rept. RM-65. 696 pp.

Anderson, B. W. and Ohmart, R. D. 1982. Revegetation for wildlife enhancement along the lower Colorado River. Final Report, USDI Bur. Reclam., Boulder City. 215 pp.

✓ Anderson, B. W. and Ohmart, R. D. 1984a. Vegetation management study for the enhancement of wildlife along the Lower Colorado River. Bureau of Reclamation, Lower Colorado Region, Boulder City, NV. Contract No. 7-07-30-V0009. 529 pp.

Anderson, B. W. and Ohmart, R. D. 1984b. Vegetation community type maps Lower Colorado River. Bur. Reclam. Lower Colorado Region, Contract No. 2-07-30-X0224. 59 pp.

✓ Anderson, B. W., Higgins, A. and Ohmart, R. D. 1977a. Avian use of salt-cedar communities in the lower Colorado River Valley. pp. 128-136. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

Anderson, B. W., Engle-Wilson, R. W., Wells, D. and Ohmart, R. D. 1977b. Ecological study of southwestern riparian habitats: techniques and data applicability. pp. 146-155. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

148 172

- Anderson, B. W., Ohmart, R. D. and Disano, J. 1978. Revegetating the riparian floodplain for wildlife pp. 318-331. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Anderson, B. W., Ohmart, R. D. and Fretwell, S. D.. 1982. Evidence for social regulation in some riparian bird populations. Amer. Natur. 120(3):340-352.
- Anderson, B. W., Ohmart, R. D. and Rice, J. 1981. Seasonal changes in avian densities and diversities. Studies in Avian Biology 6:262-264.
- Anderson, J. E. 1977. Transpiration and photosynthesis in saltcedar. Hydrology and Water Resources in Arizona and the Southwest 7:125-131.
- Anderson, J. E. 1982. Factors controlling transpiration and photosynthesis in Tamarix chinensis. Ecology 63(1):48-56.
- Anderson, T. W. 1970. Evapotranspiration losses from flood plains in the Agua Fria drainage above Lake Pleasant, Arizona. U.S. Geol. Surv. Open-file Rep. Tucson, AZ.
- Ando, K. 1980. Field survival and rooting ability of Elaeagnus angustifolia and Tamarix pentandra. Univ. of Nevada. Reno, NV. 118 pp.
- Andres, L. A. 1981a. Biological control of naturalized and native plants: Conflicting interests. pp. 341-349. In: BARC Sympos. No. 5, Biological control in crop production.
- Andres, L. A. 1981b. Conflicting interests and the biological control of weeds. pp. 11-20. In: E. Delfosse (ed.). Proc. V Intl. Symp. Biol. Control Weeds, Brisbane, Australia. July 1980.
- Arle, H. F. 1957. A summary of results of experiments and field trials pertaining to the control of saltcedar (Tamarix pentandra). Abs. Sympos. Phreatophytes. pp. 46-52. In: Symposium on Phreatophytes. Phreatophyte Subcommittee of PSIAC, presented at Southwest Reg. Meet. Amer. Geophys. Union, Feb. 14-15, 1957, Sacramento, CA.
- Arle, H. F. 1960. Saltcedar Control with Chemicals. Arizona Watershed Symposium Proc. 4:27-28.
- Barclay, G. E. 1951. Phreatophyte control methods as undertaken by the Fish and Wildlife Service. pp. 33-34. In: Pac. Southw. I.A.C. Minutes of Phreatophyte Subcommittee Mtg., Vol. I.
- Barry, V. H., Jr. 1978. Position paper: Soil Conservation Service and riparian ecosystems: A long-term view. pp. 353-358. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.

- Baum, B. R. 1967. Introduced and naturalized tamarisks in the United States and Canada (Tamaricaceae). *Baileya* 15:19-25.
- Baum, B. R. 1978. The genus Tamarix. Israel Academy of Sciences and Humanities, Jerusalem. 209 pp.
- Behnke, R. J. and Raleigh, R. F. 1978. Grazing and the riparian zone: Impact and management perspectives. pp. 263-267. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Bell, A. 1983. Native plants facing extinction. *Ecosystems* 37:21-26.
- Bennett, P. S. and W. J. Burke. 1989. Committee Reports: Tamarisk research and management. pp. 108-113. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Benson, L. 1959. Plant Classification. D. C. Heath & Co., Lexington, Mass. 688 pp.
- Bergthold, P. M. 1978. Arizona State Parks Natural Area Program. pp. 243-247. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Berry, W. L. 1970. Characteristics of salts secreted by Tamarix aphylla. *Amer. J. Bot.* 57(10):1226-1230. ✓
- Bibby, F. F. 1942. Notes on miscellaneous insects of Arizona. *J. Econ. Ent.* 54:324-333. ✓
- Blaney, H. F. 1933. Consumptive use of water by native plants growing in moist areas in southern California. *Calif. State Dept. Pub. Works, Div. of Water Resources Bull.* 44:19-25.
- Blaney, H. F. 1957. Relationship of pan evaporation to evapotranspiration by phreatophytes and hydrophytes. Phreatophyte Subcommittee of Pacific Southwest Inter-Agency Committee. 6 pp.
- Blaney, H. F. 1961. Consumptive use and water waste by phreatophytes. *J. Irrigation & Drainage Div., Proc Amer. Soc. Civil Engr.* 87(3):37-46.
- Blaney, H. F. and Criddle, W. D. 1962. Determining consumptive use and irrigation water requirements. *USDA-Agr. Res. Serv. Tech. Bull.* 1275. 50 p.
- Blaney, H. F. and Ewing, P. A. 1946. Irrigation practices and consumptive use of water in Salinas Valley, California. *USDA Bull.* 52. 81 pp.

- Blaney, H. F. and Harris, K. 1952. Consumptive use of water rates in the Lower Colorado River Basin (Provisional). In: Report on Water Supply of the Lower Colorado River Basin, Project Planning Report, Nov. 1952. US Dept. Inter., US Bur. of Relam., Region 3. 89 pp.
- Blaney, H. F. and Morin, K. V. 1942. Evaporation and consumptive use of water empirical formulas. Trans. Amer. Geo. Union. pp. 76-83.
- Blaney, H. F., Ewing, P. A., Israelsen, O. W., Rohwer, C. and Scobey, F. C. 1938. Water utilization Part III pp. 293-294, 405-424. Natl. Resources Commit., Regional Planning: Part IV--the Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas, 1936-1937. 562 pp.
- Blaney, H. F., P. A. Ewing, K. V. Morin, D. W. Bloodgood, L. H. Schoenleber, W. D. Criddle, D. C. Muckle, and F. C. Scobey. 1942a. Consumptive water use and requirements. Part III, Sect. 3. p. 170-230. In: The Pecos River Joint Investigation: Reports of the Participating Agencies. U.S. National Resource Planning Board, Washington, DC. 407 pp.
- Blaney, H. F., Ewing, P. A., Morin, K. V. and Criddle, W. D. 1942b. Consumptive water use and requirements, report of the participating agencies. The Pecos River Joint Investigation-Part X. Natl. Resources Planning Board. pp. 1-89, 117-137, 171-185. Summary, analysis, and findings. (U.S. Govt. Print. Off.). 207 pp.
- Blankenship, D. R., Teer, J. G. and Kiel, W. H., Jr. 1972. Movements and mortality of white-winged doves banded in Tamaulipas, Mexico. Trans. North Amer. Wildlife & Natural Resources Conf. 37:312-325.
- ✓ Boer, W. J. and Schmidly, D. J. 1977. Terrestrial mammals of the riparian corridor in Big Bend National park. pp. 212-217. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Bowen, I. S. 1926. The ratio of heat-losses by conduction and by evaporation from any water surface. Phys. Rev. 27:779-787.
- Bowie, J. E. and Kam, W. 1968. Use of water by riparian vegetation, Cottonwood Wash, Arizona. U.S. Geol. Surv. Water-Supply Paper 1858. 62 pp.
- Bowman, C. 1989. 1987 Tamarisk control project: Petrified Forest National Park. pp. 11-16. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Bowser, C. W. 1957. Introduction and spread of the undesirable tamarisks in the Pacific Southwest section of the United States and comments concerning the plants' influence upon the indigenous vegetation. Am. Geophys. Union Trans. 38(3):415-416.

- Brady, W., Patton, D. R. and Paxson, J. 1985. ~~The development of south-~~  
western riparian gallery forest. pp. 39-43. In: Proc. First North  
American Riparian Conf, April 16-18, 1985, Tucson, Ariz. 521 pp.
- Brooks, F. L., Jr. and Dellberg, R. 1969. Windbreaks of tamarisk lead rail-  
road safely through desert. Soil Conserv. 35(3):55-56.
- Brown, B. 1989. Economic analysis of harmful and beneficial aspects of  
saltcedar. Final Rept. to Bur. Reclam.-USDI, Lower Colorado Reg. Off.,  
Boulder City, NV, Contract No. 8-CP-30-05800, prepared by Great Western  
Research, Inc., Mesa, AZ. 261 pp.
- Brown, D. E. 1973. The loss and deterioration of Arizona's riparian commun-  
ities and resulting effects on wildlife with particular reference to the  
whitewing dove. Proc. Western Assoc. State Game and Fish Commissioners  
53:311-314.
- Brown, D. E., Blankenship, D. R., Evans, P. K., Kiel, W. H., Jr., Waggerman,  
G. L. and Winkler, C. K. 1977a. White-winged dove. Chapt. 8,  
pp. 247-266. In: Sanderson, G. C. (ed.), Management of migratory shore  
and upland game birds in North America. Internat. Assoc. Fish and  
Wildlife Agencies and the US Dept. Inter., Fish and Wildl. Serv. 358 pp.
- Brown, D. E., Carmony, N. E. and Turner, R. M. 1977b. Inventory of ripar-  
ian habitats. pp. 10-13. In: Johnson, R. R. and Jones, D. A. (Tech.  
coord.), Importance, preservation and management of riparian habitat: A  
symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For.  
Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Brown, D. E., Lowe, C. H. and Hausler, J. F. 1977c. Southwestern riparian  
communities: Their biotic importance and management in Arizona.  
pp. 201-211. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Impor-  
tance, preservation and management of riparian habitat: A symposium.  
July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt.  
Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Brown, J. G. 1953. Parasite for salt cedars. Arizona Farmer 32(20):22-23.
- Bureau of Reclamation. 1964. Pacific Southwest Water Plan. Appendix of  
August 1963, as modified January 1964. USDI-Bur. Reclam. Rept. 282 p +  
tables & figs.
- Bureau of Reclamation. 1966. Definite plan report, Pecos River basin water  
salvage project, New Mexico-Texas. Vol. 1. USDI-Bur. Reclam, Region 5,  
June 1966. 36 p + exhibits A thru J. (mimeo)
- Bureau of Reclamation. 1972. Phreatophyte investigations, Bernardo evapo-  
transpirometers. Progress report. Albuquerque Development Office.  
(mimeo). 106 pp.
- Bureau of Reclamation. 1973. Phreatophyte investigations, Bernardo evapo-  
transpirometers[Second progress report, 1969-1973 Middle Rio Grande  
Project Office (mimeo). 50 pp.

- Bureau of Reclamation. 1977. Operation and maintenance program for the Rio Grande-Velarde to Caballo Dam; Rio Grande and Middle Rio Grande Projects. Environmental Impact Statement, Vol. I, Sect. A-H. Bur. Reclam.-USDI, Amarillo, TX. 434 p.
- Bureau of Reclamation. 1979. Pecos River Basin Water Salvage Project: Final environmental statement. Southwest Regional Office, Amarillo, TX. (mimeo).
- Bureau of Reclamation. 1986. Progress Report, Revegetation via tree cuttings - 1976-1985. Southw. Reg., Rio Grande Proj., El Paso, TX. 42 p.
- Bureau of Reclamation. 1990. Vegetation management study - Lower Colorado River. Phase I Report. USDI-Bur. Reclam., Lower Colorado Region. 94 p. + 21 maps.
- Burkart, A. 1976. A monograph of the genus Prosopis (Leguminosae subfam. Mimosoideae). J. Arnold Arboretum 57(3/4):217-525.
- Burke, W. J. 1989. Tamarisk and its control at Lake Mead National Recreation Area. pp. 17-19. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Burkham, D. E. 1970. Precipitation, streamflow, and major floods at selected sites in the Gila River drainage basin above Coolidge Dam, Arizona. USDI-Geolog. Surv. Prof. Paper 655-B. 33 p.
- Burkham, D. E. 1972. Channel changes of the Gila River in Safford Valley, Arizona--1846-1970. USDI-Geolog. Surv. Prof. Paper 655-G. 24 p + 5 plates. *pg 56*
- Burkham, D. E. 1976a. Flow from small watersheds adjacent to the study reach of the Gila River Phreatophyte Project, Arizona. USDI-Geolog. Surv. Prof. Paper 655-I. 19 p + 2 plates.
- Burkham, D. E. 1976b. Hydraulic effects of changes in bottom-land vegetation on three major floods, Gila River in Southeastern Arizona. USDI-Geolog. Surv. Prof. Paper 655-J. 14 p. + 2 plates. ✓
- Burkham, D. E. 1976c. Effects of changes in an alluvial channel on the timing, magnitude, and transformation of flood waves, southeastern Arizona. U.S. Dept. Interior, Geological Surv. Professional Paper 655-K. 25 pp.
- Busby, F. E. and Schuster, J. L. 1971. Woody phreatophyte infestation of the Middle Brazos River flood plain. J. Range Manage. 24: 285-287.
- Busby, F. E. and Schuster, J. L. 1973. Woody phreatophytes along the Brazos River and selected tributaries above Possum Kingdom Lake. Texas Water Development Board Rept. 168. 41 pp. ✓

- Butler, W. I., Jr. 1977. A white-winged dove nesting study in three riparian communities on the Lower Colorado River. M.S. Thesis. Arizona State Univ. 78 pp.
- Campbell, C. J. 1966. Periodic mowings suppress tamarisk growth, increase forage for browsing. U.S. For. Serv. Res Note RM-76. 4 pp.
- Campbell, C. J. 1970. Ecological implications of riparian vegetation management. J. Soil Water Conserv. 25:49-52.
- Campbell, C. J. and Dick-Peddie, W. A. 1964. Comparison of phreatophyte communities on the Rio Grande in New Mexico. Ecology 45(3):492-502.
- Campbell, C. J. and Green, W. 1968. Perpetual succession of stream channel vegetation in a semi-arid region. J. Ariz. Acad. Sci. 5:86-98.
- Carman, J. G. and Brotherson, J. D. 1982. Comparisons of sites infested and not infested with saltcedar (Tamarix pentandra) and Russian olive (Elaeagnus angustifolia). Weed Sci. 30(4):360-364.
- Carothers, S. W. 1977. Importance, preservation and management of riparian habitats: An overview. pp. 2-4. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Carothers, S. W., and Johnson, R. R. 1971. A summary of the Verde Valley breeding bird survey. Ariz. Game and Fish Dept. Land and Water Proj. Investigations. Verde River Studies. Proj. FS-16-10. 20 pp.
- Carothers, S. W., and Johnson, R. R. 1975. Water management practices and their effects on nongame birds in range habitats. pp. 210-222. In: Proc. Symp. on Management of Forest and Range Habitats for Nongame Birds. USDA For. Serv. Gen. Tech. Rept. No. 1. Washington, DC.
- Carothers, S. W., Johnson, R. R. and Aitchison, S. W. 1974. Population structure and social organization of southwestern riparian birds. Amer. Zool. 14: 97-108.
- Carothers, S. W., Mills, G. S. and Johnson, R. R. 1989. The creation and restoration of riparian habitat in southwestern arid and semi-arid regions. pp. 359-376. In: Kusler, J. A. and Kentula, M. E., Wetland Creation and Restoration: The Status of the Science. EPA/600/3-89/038. U.S. Environ. Protect. Agency, Corvallis, OR. Vol. I, 473 p.
- Christensen, E. M. 1962. The rate of naturalization of Tamarix in Utah. Am. Midl. Nat. 68: 51-57.
- Cinnamon, S. K. 1989. Wupatki National Monument tamarisk and camelthorn eradication program 1983-88. pp. 20-24. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.

- Coffey, J. 1989. Summary report on tamarisk control: Joshua Tree National Monument. pp. 25-27. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Cohan, D. R., Anderson, B. W. and Ohmart, R. D. 1978. Avian population responses to salt cedar along the Lower Colorado River. pp. 371-382. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wet-lands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp. ✓
- Comrack, L. 1986. Exotic plant control-Tamarisk removal, Anza Borrego Desert State Park, 1985/86, 1984/85, 1983/84. In: Statewide Resource Manage. Progr., Proj. Status Report. State of California. 14 pp.
- Comrack, L. 1988a. Statewide resource management program, project status report. Picacho State Recreation Area, California. ✓
- this one Comrack, L. 1988b. Statewide resource management program, project status report. Exotic plant control - tamarisk removal, Anza Borrego State Park, California.
- Conine, K. H., Anderson, B. W., Ohmart, R. D. and Drake, J. F. 1978. Responses of riparian species to agricultural habitat conversions. pp. 248-262. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wet-lands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Cottam, C. and Trefethen, J. B. 1968. Whitewings, The life-history, status, and management of the white-winged dove. D. Van Nostrand Company, Inc. 348 pp. ✓
- Coulson, J. R. and Soper, R. S. 1989. Protocols for the introduction of biological control agents in the U.S. pp. 2-35. In: Kahn, R. P. (ed.), Plant protection and quarantine, vol. III Special Topics. CRC Press, Inc., Boca Raton, FL. ✓
- Crins, W. L. 1989. The Tamaricaceae in the southeastern United States. J. Arnold Arboretum 70:403-425.
- 8 or 1881 - diff. publ - d here  
Cronquist, A. 1988. The evolution and classification of flowering plants. New York. 555 pp.
- Cruff, R. W. and Thompson, T. H. 1967. A comparison of methods of estimating potential evapotranspiration for climatological data in arid and subhumid environments. USDI-Geolog. Surv. Prof. Paper 1939-M. 28 p.
- Culler, R. C. 1965. The Gila River phreatophyte project. Ariz. Watershed Symp. Annu. Proc. 9: 33-38.

- Culler, R. C., Burkham, D. E. and Collings, M. R. 1970. Objectives, methods, and environment--Gila River phreatophyte project, Graham County, Arizona. U.S. Geol. Surv. Prof. Paper 655-A. 25 pp. ✓
- Culler, R. C., Hanson, R. L. and Jones, J. E. 1976. Relation of the consumptive use coefficient to the description of vegetation. Water Resources Research 12(1):40-46.
- Culler, R. C., Hanson, R. L., Myrick, R. M., Turner, R. M. and Kipple, F. P. 1982. Evapotranspiration before and after clearing phreatophytes, Gila River Flood Plain, Graham County, Arizona. Gila River Phreatophyte Project. USDI, U.S. Geolog. Surv. Prof. Paper 655-P. 67 pp.
- Cunningham, S. C. 1986. The comparative feeding and nesting ecology of mourning and white-winged doves in the Buckeye-Arlington Valley area of Arizona. Ariz. Game Fish Dept. Contract 0203. 121 pp.
- Cuthbertson, E. G. 1948. The athel tree (Tamarix aphylla articulata), valuable for shelter belts. Agr. Gaz. N. S. Wales 59: 395-398, 402.
- Cutler, M. R. 1979. The need to move from mitigation to multi-objective planning. pp. 54-58. In: Swanson, G. A. (Tech. coord.), The mitigation symposium: A national workshop on mitigating losses of fish and wildlife habitats, July 16-20, 1979, Fort Collins, CO. USDA For. Serv., Rocky Mtn. For. Range Expt. Sta., Ft. Collins, CO. Gen. Tech. Rept. RM-65. 696 pp.
- Davenport, D. C., Hagan, R. M., Gay, L. W., Bonde, E. K., Kreith, F. and Anderson, J. E. 1978. Factors influencing usefulness of antitranspirants applied on phreatophytes to increase water supplies. United States Office of Water Research and Technology Completion, California Water Resources Center, Davis, CA. Rept. C-6030. 181 pp.
- Davila, V. Jr. 1989. Tamarisk eradication efforts at Guadalupe Mountains National Park, Texas. pp. 28-32. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Davis, C. A. 1974. Mourning dove foods in semi-desert, South-central New Mexico. J. Wildlife Manage. 34(4):941-944.
- Davis, D. G. 1978. Environmental Protection Agency programs relating to riparian ecosystems. pp. 336-340. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Davis, G. A. 1977. Management alternatives for the riparian habitat in the Southwest. pp. 59-67. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

- Decker, J. P. and Wetzel, B. F. 1957. A method for measuring transpiration of intact plants under controlled light, humidity, and temperature. *Forest Sci.* 3: 350-354.
- Decker, J. P. and Wien, J. D. 1960. Transpirational surges in Tamarix and Eucalyptus as measured with an infrared gas analyzer. *Plant Physiol.* 35(3):340-343.
- Decker, J. P., Gaylor, W. G. and Cole, F. D. 1962. Measuring transpiration of undisturbed tamarisk shrubs. *Plant Physiol.* 37(3):393-397.
- DeLoach, C. J. 1978. Considerations in introducing foreign biotic agents to control native weeds of rangelands. pp. 39-50. In: Freeman, T. E. (ed.), *Proc. IV Internat. Symp. Biol. Control Weeds*, Aug. 30-Sept. 2, 1976 Gainesville, FL.
- DeLoach, C. J. 1981. Prognosis for biological control of weeds of southwestern U.S. rangelands. pp. 175-199. In: Delfosse, E. (ed.), *Proc. V Internat. Symp. Biological Control Weeds*, Brisbane, Australia. July 1980.
- DeLoach, C. J. 1984. Development of criteria for selection of weed species for classical biological control research. pp. 119-123. In: Jackson, R. D., et al. (eds.), *Research Planning Conf. Biological Control*, March 20-24, 1984. USDA, Agric. Res. Serv. 473 pp.
- DeLoach, C. J. 1990. Prospects for biological control of saltcedar (Tamarix spp.) in riparian habitats of the southwestern United States. *Proc. VII Internat. Symp. Biol. Control Weeds*, 6-11 March 1988, Rome, Italy. pp. 307-314.
- DeLoach, J. C., Boldt, P. E., Cordo, H. A., Johnson, H. B. and Cuda, J. P. 1986. Weeds common to Mexican and U.S. rangelands: Proposals for biological control and ecological studies. pp. 49-68. In: *Proc. Sympos. Manage. & Utiliz. Arid Land Plants*, Saltillo, Mexico, Feb. 18-22, 1985. USDA For. Serv., Rocky Mtn. For. & Range Expt. Stn. U.S. For. Serv. Gen. Tech. Rept. RM-135.
- DeLoach, C. J., Farmer, D. B. and Robbins, T. O. (manuscript a). Number and value of shade and ornamental trees in Texas.
- DeLoach, C. J., Wienhold, C. and Farmer, D. B. (manuscript b). Number and value of shade and ornamental trees in Arizona and parts of surrounding states. 25 pp.
- DeLoya, M. C. 1985. Riparian ecosystems in Mexico: Current status and future direction. pp. 9-12. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), *Riparian ecosystems and their management: Reconciling conflicting uses*. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. Rocky Mtn. For. Range Expt. Sta. Tech. Rept. RM-120. Fort Collins, CO. 523 pp.

Denyes, H. 1956. Natural terrestrial communities of Brewster Co., Texas, with special reference to the distribution of mammals. Amer. Midl. Natur. 55:289-320.

Ditton, R. B. and Schmidly, D. J. 1977. A user-resource analysis of Amistad Recreation Area (Texas). Rept. prepared for Off. Natural Resources, Southw. Reg., Natl. Park Serv., Santa Fe, NM. (contract no. CX702960169). 207 pp.

Ditton, R. B., Schmidly, D. J., Boeer, W. J. and Graefe, A. R. 1977. A survey and analysis of recreational and livestock impact on the riparian zone of the Rio Grande in Big Bend National Park. pp. 256-266. Proc.: Symp. on River Recreation, Management and Research. USDA For. Serv. Gen. Tech. Rept. NC-28.

Dunks, J. H. 1977. The white-winged dove harvest in Texas. TX Parks and Wildlife Dept., Fed. Aid Proj. W-30-R-30 "Survey, status of the white-winged dove in Texas." Attach. 1. 21 pp.

Eagleman, J. R. 1967. Pan evaporation, potential and actual evapotranspiration. J. Appl. Meteorol. 6:482-488.

Eakin, M. E. and Brown, C. B. 1939. Silting of reservoirs. USDA Tech. Bull. 524 (revised).

Economic Research Service. 1984. Honey: Background for 1985 farm legislation. USDA-Econ. Res. Serv., Agric. Info. Bul. 465. 30 pp.

Elmendorf, H. B., Brown, A. F., Koogler, J. G., Palmer, R. Q., Timmons, F. L., Crawford, P. W., Marshall, C. G., Theis, C. V., Gangwer, V. O., Rork, C. F. and Cook, L. F. 1951. Report to Salt Cedar Interagency Council. Salt Cedar Interagency Task Force, New Mexico; Albuquerque, Feb. 1, 1951. 28 p. + 81 p. append. (mimeo).

Engle-Wilson, R. W. 1981. Comparison of bird communities in saltcedar and honey mesquite along the Lower Colorado, Verde, and Gila Rivers. M.S. Thesis. Ariz. State Univ., Tucson. 67 pp.

Engel-Wilson, R. W. and Ohmart, R. D. 1978a. Assessment of vegetation and terrestrial vertebrates along the Rio Grande between Fort Quitman, TX and Hazienda, TX. United States Section International Boundary and Water Commission. Contract No. IBM 77-17. 80 pp. + App. A (7 p.), App. B (88 p).

✓ Engel-Wilson, R. W. and Ohmart, R. D. 1978<sup>b</sup>. Floral and attendant faunal changes on the lower Rio Grande between Fort Quitman and Presidio, Texas. pp. 139-147. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.

Everitt, B. L. 1980. Ecology of saltcedar - a plea for research. Environ. Geol. 3: 77-84.

- Everitt, J. H. and C. J. DeLoach. 1990. Remote sensing of Chinese tamarisk (*Tamarix chinensis*) and associated vegetation. *Weed Sci.* 38:273-278.
- Everitt, J. H., DeLoach, C. J. and Hart, W. G. 1990. Using remote sensing for detecting brush and weeds on rangelands in the southwestern United States. pp. 585-593. In: Delfosse, E. S. (ed.), *Proc. VII Internatl. Symp. Biol. Control Weeds*, March 6-11, 1988. Rome, Italy. 701 p.
- Fenchel, G. A. and Swenson, E. 1989. Establishment and propagation techniques for cottonwoods and black willows for use in southwestern riparian restoration. pp. 190-191. In: *Practical Approaches to Riparian Resource Management: an Educational Workshop*. Bur. Land Manage., Billings, MT.
- Fenchel, G. A., Oaks, W. and Swenson, E. 1989. Selecting desirable woody vegetation for environmental mitigation and controlling wind erosion and undesirable plants in the Rio Grande and Pecos River Valleys of New Mexico, Five year interim report (1983-87). USDA-SCS, Plant Materials Center, Los Lunas, NM. 49 p.
- Fish and Wildlife Service. 1961. Abstracts of mourning dove literature USDI Rept. 136. 155 pp.
- Fish and Wildlife Service. 1979. Unique wildlife ecosystems of Texas: Concept plan. USDI, Reg. 2. 164 pp.
- Fish and Wildlife Service. 1980. Preservation of areas of important fish and wildlife habitat: Cameron, Hidalgo, Starr, and Willacy Counties, Texas. USDI, Albuquerque. 92 pp.
- Fish and Wildlife Service. 1981. Clearing of phreatophytic vegetation from the Salt and Gila Rivers, Ninety-First Avenue to Gillespie Dam, Maricopa County, Arizona. Environmental Impact Statement. Fish and Wildlife Service-USDI, Phoenix, AZ. Vol 1: 155 pp. + 24 maps, Vol 2: 91 pp.
- Fish and Wildlife Service. 1988. 1985 National survey of fishing, hunting, and wildlife associated recreation. USDI-Fish and Wildlife Serv. 167 pp.
- Fish and Wildlife Service. 1989. 1985 National survey of fishing, hunting, and wildlife associated recreation, Arizona. Washington, DC. Issued March 1989. 81 pp.
- Fitzsimmons, S. J., Stuart, L. I. and Wolff, P. C. 1975. A guide to the preparation of the social well-being account, social assessment manual. Abt Associates, Inc., prepared for U.S. Bur. Reclam., Denver, CO. Contract No. 14-06-D-7342(5). 279 pp.
- Ffolliott, P. F. and Thorud, D. B. 1974. Vegetation management for increased water yield in Arizona. Univ. Arizona Agric. Expt. Stn., Tech. Bull. 215. 38 pp.

- Fleming, C. M. 1989. Status report on Tamarix in Big Bend National Park. pp. 33-35. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv., Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Fox, K. 1977. Importance of riparian ecosystems: Economic considerations. pp. 19-22. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Frezzi, M. J. 1942. Death of tamarisk caused by Botryosphaeria tamaricis in Corrientes, Argentina. Rev. Argentina de Agron. 9: 100-113.
- Frost, K. R. 1960. The effects of chlorophenoxy herbicides on saltcedar cuttings grown in the greenhouse. M.S. Thesis, Univ. Arizona, Tucson. 42 pp.
- Frost, K. R., Jr., and Hamilton, K. C. 1960. Report on the Wellton-Mohawk salt cedar clearing studies. Agric. Expt. Sta., Univ. Arizona, Tucson, Rept. 193. 54 pp.
- Gallucci, T. 1978. The biological and taxonomic status of the white-winged doves of the Big Bend of Texas. M.S. Thesis. Sul Ross State University. 208 pp.
- Gary, H. L. 1960. Utilization of five-stamen tamarisk by cattle. USDA For. Serv., Rocky Mtn. For. Range Expt. Stn., Fort Collins, CO. Research Note 51. 4 pp.
- Gary, H. L. 1962. Removal of Tamarisk (Tamarix pentandra)-reduces water-table fluctuations in central Arizona. USDA Forest Serv. Rocky Mtn. For. & Range Expt. Sta. Res. Note No. 81. 6 pp.
- Gary, H. L. 1963. Root distribution of five-stamen tamarisk, seepwillow, and arrowweed. For. Sci. 9(3):311-314.
- Gary, H. L. and Campbell, C. J. 1965. Water table characteristics under tamarisk (Tamarix pentandra) in Arizona. USDA Forest Serv. Res. Notes RM-58. 7 pp.
- Gary, H. L. and J. S. Horton. 1965. Some sprouting characteristics of five-stamen tamarisk. USDA-For. Serv. Rocky Mtn. For. Range Expt. Stn. U.S. For. Serv. Research Note RM-3. 7 pp.
- Gatewood, J. S., Robinson, T. W., Colby, B. R., Herr, J. D. and Halpenny L. C. 1950. Use of water by bottomland vegetation in lower Safford Valley, Arizona. U.S. Geol. Survey Water-Supply Paper 1103. 210 pp.

Gay, L. W. 1985. Evapotranspiration from saltcedar along the lower Colorado River. pp. 171-174. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. USDA-For. Serv., Rocky Mtn. For. Range Expt. Sta. Fort Collins, CO. Gen. Tech. Rept. RM-120. 523 pp.

Gay, L. W. and Fritschen, L. J. 1979. An energy budget analysis of water use by saltcedar. Water Resources Res. 15(6):1589-1592.

Gay, L. W. and Hartman, R. K. 1982. Et measurements over riparian saltcedar on the Colorado River. Hydrology and Water Resources in Arizona and the Southwest 12:9-15. ✓

Gay, L. W. and Sammis, T. W. 1977. Estimating phreatophyte transpiration. Hydrology and Water Resources in Arizona and the Southwest 7: 133-139.

Gay, L. W., Sammis, T. W. and Ben-Asher, J. 1976. An energy budget analysis of evapotranspiration from saltcedar. Hydrology and Water Resources in Arizona and the Southwest 7: 133-139.

George, R. R. 1985. White-winged dove management in Texas with implications for northeastern Mexico. In: First Regional Conf. Rio Grande States on Parks and Wildlife, Nov. 5-8, 1985, Laredo, TX. 139 pp. (mimeo).

George, R. R. 1988a. Status of white-winged and white-tipped doves in Texas, 1988. Tx. Parks and Wildlife Dept., Austin, TX. 7-D-690-06-16-88 (mimeo). 4 pp.

George, R. R. 1988b. White-winged dove habitat. Texas Parks and Wildlife Dept., Austin, TX. 2 pp. (mimeo).

✓ Gerling, D. and Kugler, J. 1973. Evaluation of enemies of noxious plants in Israel as potential agents for the biological control of weeds. Final Tech. Rept., 1 Sept. 1970 - 31 Aug. 1973, Tel Aviv Univ. Dept. Zoology, Grant No. FG-IS-298, USDA, P.L. 480, Proj. #A10-ENT-36. 241 pp.

W Gerling, D., Kugler, J. and Lupo, A. 1976. The gall insects and mites that occur on Tamarix spp. in Israel and the Sinai. Boll. Lab. Entomol. Agrar (Portici) 33:53-79.

Gilluly, R. H. 1971. Wildlife versus irrigation. Science News 99: 184-185.

Ginzburg, C. 1967. Organization of the adventitious root apex in Tamarix aphylla. Amer. J. Bot. 54(1):4-8.

Glinski, R. L. 1977. Regeneration and distribution of sycamore and cottonwood trees along Sonoita Creek, Santa Cruz County, Arizona. pp. 116-123. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

- Glinski, R. L. and Ohmart, R. D. 1984. Factors of reproduction and population densities in the Apache cicada (Diceroprocta Apache.). Southw. Natur. 29(1):73-79.
- Goeden, R. D. 1978. Biological control of weeds. Part II, pp. 357-506. In: Clausen, C. P. (ed.), Introduced Parasites and Predators of Arthropod Pests and Weeds: A World Review. USDA Agric. Res. Serv., Agric. Handbook 480. 545 pp.
- Goeden, R. D. 1983. Critique and revision of Harris' scoring system for selection of insect agents in biological control of weeds. Protect. Ecol. 5:287-301.
- ✓ Goeden, R. D. and S. M. Louda. 1976. Biotic interference with insects imported for weed control. Ann. Rev. Entomol. 21:325-342. ✓
- Good, R. 1974. The Geography of the Flowering Plants. Longman Group Ltd., London. 557 p.
- Goodwin, D. 1977. Pigeons and doves of the world. 2nd Ed. Cornell Univ. Press, Ithaca. British Museum Natural History. 446 pp.
- Graf, W. L. 1979. Potential control measures for phreatophytes in the channels of the Salt and Gila Rivers. Dept. Geography, Arizona State Univ., Tempe. Rept. to Corps of Engineers, Contract No. DACW09-79-C-0059.
- Gray, R. L., Snieckus, R. and Wilcox, G. 1984. Riparian vegetation in California. pp. 26-32. In: California-Nevada Wildlife Transactions, Reno, NV.
- Griffing, J. P. and Davis, C. A. 1974. Mourning dove foods in an uncultivated area of New Mexico. J. Wildl. Manage. 38(2):375-376.
- Haase, E. F. 1972. Survey of floodplain vegetation along the lower Gila River in southwestern Arizona. J. Ariz. Acad. Sci. 7(2):75-81.
- Habib, R. 1983. The bionomics of Psectrosema spp. (Diptera: Cecidomyiidae) reared from galls on Tamarix spp. in Pakistan. Bul. Entomol. Res. 73:457-463.
- ✓ Habib, R. and Hasan, S. A. 1982. Insect enemies attacking tamarisk, Tamarix spp., in Pakistan. Pakistan Station, Commonw. Inst. Biol. Control, Rawalpindi. Final Rept. June 1975-June 1980. 138 p + 32 p appendix.
- Hanson, R. O. and Dawdy, D. R. 1976. Accuracy of evapotranspiration rates determined by the water-budget method, Gila River flood plain, southeastern Arizona. U.S. Geol. Surv. Prof. Paper 655-L 35 pp.
- Harborne, J. B. 1975. Flavonoid bisulphates and their co-occurrences with ellagic acid in the Bixaceae, Frankeniaceae and related families. Phytochem. 14(56):1331-1337.

- Harris, K. M. 1983. Descriptions of Psectrosema spp. (Diptera: Cecidomyiidae) reared from galls on Tamarix spp. in Pakistan, including four new species. *Bul. Entomol. Res.* 73:447-456.
- Harris, P. 1973. The selection of effective agents for the biological control of weeds. *Canadian Entomol.* 105:1485-1503. ✓
- Harris, P. 1979. The cost of biological control of weeds by insects in Canada. *Weed Sci.* 27:242-250.
- Harris, P. 1988. Environmental impact of weed-control insects. *BioScience* 38(8):542-548.
- Hayden, B. 1976. The dynamics of an exotic on a man-altered system: Tamarix in the Grand Canyon. *Natl. Park Serv. Rept.* Unpublished. 8 pp.
- Hays, F. and J. Mitchell. 1989. Tamarisk eradication in Zion National Park. pp. 36-38. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), *Proc. Tamarisk Conf.* Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. *Natl. Park. Resources Studies Unit Spec. Rept. No. 9.* 141 pp.
- Hefley, H. M. 1937. The relations of some native insects to introduced food plant. *J. Animal Ecol.* 6: 138-144.
- Hem, J. D. 1967. Composition of saline residues on leaves and stems of salt-cedar (Tamarix pentendra Pallas.). *U.S. Geol. Surv. Prof. Paper* 491-C. 9 pp.
- Herbst, R. L. 1978. Keynote address: A systems approach to management strategies. pp. 5-12. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), *Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems*, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. *Gen. Tech. Rept. WO-12.* 410 pp.
- Hildebrandt, T. D. and Ohmart, R. D. 1982. Final report. Biological resource inventory (vegetation and wildlife) Pecos River Basin, New Mexico and Texas. *Bur. Reclam. Contract No. 9-07-57-V0567.* 160 pp. ✓
- ✓ Hink, V. C. and Ohmart, R. D. 1984. Middle Rio Grande biological survey. Final report. *U.S. Corps. Eng.* 193 pp.
- Hirsch, A. and Segelquist, C. A. 1978. Position paper: Protection and management of riparian ecosystems: Activities and views of the U.S. Fish and Wildlife Service. pp. 344-352. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), *Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems*, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. *Gen. Tech. Rept. WO-12.* 410 pp.

- Holland, J. S. 1989. Status of saltcedar (Tamarix ramosissima) within Glen Canyon National Recreation Area. pp. 39-41. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Hollingsworth, E. B. 1973. Summary report phreatophyte research, Los Lunas, New Mexico 1961-1972. USDA Agric. Res. Serv., Crops Research Div. Unpubl. report. 18 pp.
- Hollingsworth, E. B., Quimby, P. C. and Jaramillo, D. C. 1979. Control of saltcedar by subsurface placement of herbicides. J. Range Manage. 32(4):288-291.
- Homerstad, G. E., Waggener, G. L. and George, R. R. 1988. The reforestation of cropland in the Lower Rio Grande Valley of Texas with emphasis on white-winged dove nesting habitat. Second Reg. Conf. of the Rio Grande Border States on Parks and Wildlife. Saltillo, Coahuila, Mexico. 13 pp.
- Hopkins, H. H. and Tomanek, G. W. 1957. A study of the woody vegetation at Cedar Bluff Reservoir. Trans. Kansas Acad. Sci. 60(4):351-359.
- Hopkins, L. and Carruth, L. A. 1954. Insects associated with saltcedar in southern Arizona. J. Economic Entomol. 47(6):1126-1129.
- Horton, J. S. (compiler). 1973. An abstract bibliography: Evapotranspiration and water research as related to riparian and phreatophyte management. USDA For. Serv., Rocky Mtn. For. & Range Expt. Stn. Misc. Pub. No. 1234. 192 pp.
- Horton, J. S. 1976. Management of moist-site vegetation for water: Past history, present status, and future needs. U.S. For. Serv. Reg. 5, Contract No. GPO 833-665, San Francisco, CA. U.S. Govt. Print. Ofc. 41 pp.
- Horton, J. S. 1977. The development and perpetuation of the permanent tamarisk type in the phreatophyte zone of the southwest. pp. 124-127. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Horton, J. S. and Campbell, C. J. 1974. Management of phreatophyte and riparian vegetation for maximum multiple use values. USDA For. Serv. Res. Paper RM-117. 21 pp.
- Horton, J. S., Mounts, F. C. and Kraft, J. M. 1960. Seed germination and seedling establishment of phreatophyte species. USDA For. Serv., Rocky Mtn. For. & Range Expt. Sta. Paper No. 48. 26 pp.
- Howard, S. W., Dirar, A. E., Evans, J. O. and Provenza, F. D. 1983. The use of herbicides and/or fire to control saltcedar (Tamarix). pp. 65-72. Proc. Western Soc. Weed Sci.

Hubbard, J. P. 1977. Importance of riparian ecosystems: Biotic considerations. pp. 14-18. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

Hubbs, C., Miller, R. R., Edwards, R. J., Thompson, K. W., Marsh, E., Garrett, G. P., Powell, G. L., Morris, D. J. and Zerr, R. W. 1977. pp. 91-97. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

Huffaker, C. B. 1959. Biological control of weeds with insects. Ann. Rev. Entomol. 4:251-276. ✓

Huffaker, C. B. and Kennett, C. E. 1959. A ten-year study of vegetational changes associated with biological control of Klamath weed. J. Range Manage. 12:69-82. ✓

Hughes, E. E. 1965. Basal and stump sprays for control of saltcedar (Tamarix pentandra). Weeds 13:388-340.

Hughes, E. E. 1966. Research in chemical control of various phreatophytes. pp. 19-25. In: Phreatophyte Sympos., Pacific Southw. Inter-Agency Committee. Albuquerque, NM, Aug. 30, 1966.

Hughes, E. E. 1968. Hygroscopic additives to phenoxy herbicides for control of saltcedar. Weed Sci. 16:486-488.

Hull, H. M., Morton, H. L. and Martin, R. D. 1974. Response of saltcedar to foliar application of herbicides in a polypropylenedial carrier. Weed Abstr. 25:301.

Humburg, N. E., Colby, S. R., Hill, E. R., Kitchen, L. M., Lym, R. G., McAvoy, W. J., and Prasad, R. 1989. Herbicide Handbook. Weed Sci. Soc. Amer., Champaign, IL. 301 p.

✓ Hunter, W. C. 1984. Status of nine bird species of special concern along the Colorado River. State of Calif., Resources Agency, Dept. Fish and Game. 63 pp.

Hunter, W. C., Anderson, B. W. and Ohmart, R. D. 1985. Summer avian community composition of Tamarix habitats in three southwestern desert riparian systems. pp. 128-134. Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. Rocky Mtn. For. Range Expt. Sta., Fort Collins, CO. Gen Tech. Rept. RM-120. 523 pp.

Irvine, J. R. and West, N. E. 1979. Riparian tree species distribution and succession along the lower Escalante River, Utah. Southw. Natur. 24(2):331-346.

- Jahn, L. R. 1979. Summary of the symposium and recommendations for improving mitigation in the future. pp. 6-18. In: Swanson, G. A. (Tech. coord.), The mitigation symposium: A national workshop on mitigating losses of fish and wildlife habitats, July 16-20, 1979, Fort Collins, CO. USDA For. Serv., Rocky Mtn. For. Range Expt. Sta., Ft. Collins, CO. Gen. Tech. Rept. RM-65. 696 pp.
- Jahrsdoerfer, S. E. and Leslie, D. M. 1988. Tamaulipan brushland of the lower Rio Grande Valley of South Texas: description, human impacts, and management options. USDI Fish and Wildl. Serv. Biolog. Rept. 88(36). 63 pp.
- Jakle, M. D. and Gatz, T. A. 1985. Herpetofaunal use of four habitats of the Middle Gila River drainage, Arizona. pp. 355-358. Proc. First North American Riparian Conf., April 16-18, 1985, Tucson, AZ. 521 pp.
- Jensen, M. E. (Chm.). 1966. Evapotranspiration and its role in water resources management. Conf. Proc. Amer. Soc. Agric. Eng., Dec. 5-6, 1966, Chicago, IL. 64 pp.
- Jensen, M. E. (ed.). 1973. Consumptive use of water and irrigation water requirements. New York, Amer. Soc. Civil Engineers. 215 p.
- Jensen, M. E. and Haise, H. R. 1963. Measuring evapotranspiration from solar radiation. Amer. Soc. Civil Engineers, J. Irrig. Drainage Div. 89:15-41.
- Johns, E. L. (ed.). 1989. Water use by naturally occurring vegetation, including an annotated bibliography. Amer. Soc. Civil Engr., New York, NY. 32 p. + 307 abstracts.
- Johnson, B., Bliss, J. H. and Wilson, J. C. 1955. A plan for the initial development of water salvage and salinity alleviation action programs, Pecos River Basin. Pecos River Commission, Carlsbad, NM. 18 p. + 7 maps. (mimeo)
- Johnson, R. R. 1970. Tree removal along southwestern rivers and effects on associated organisms. Amer. Phil. Soc., Yearb. 1970. pp. 321-322.
- Johnson, R. R. and Jones, D. A. (Tech. coord.). 1977. Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Johnson, R. R. and McCormick, F. J. (Tech. coord.). 1978. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Dec. 11-13, 1978, Callaway Gardens, GA. Proc. Symp. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Johnson, R. R., Haight, L. T. and Simpson, J. M. 1977. Endangered species vs. endangered habitats: A concept. pp. 68-79. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

- Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.). 1985. Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, AZ. USDA For. Serv. Gen. Tech. Rept. RM-120. 523 pp.
- Johnston, M. C. 1963. Past and present grasslands of southern Texas and northeastern Mexico. *Ecology* 44(3):456-466.
- Jones, B. K. and Glinski, P. C. 1985. Microhabitats of lizards in a southwestern riparian community. pp. 342-346. *In*: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.). 1985. Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conference, April 16-18, 1985, Tucson, AZ. USDA For. Serv. Gen. Tech. Rept. RM-120. 523 pp.
- Jones, V. E., Meadors, C. H., Jacoby, P. W., and Fisher, C. E. 1978. Effects of pelleted herbicides on six hard to control brush species. pp. 191-192. Proc. 31st Ann. Mtg. Southern Weed Sci. Soc.
- Jonez, A. R., Sharpe, F. P., Strauss, P. and Deason, W. O. 1978. Interaction of water management and riparian ecosystems: Attitudes, practices, and effects. pp. 284-288. *In*: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Julien, M. H. 1987. Biological Control of Weeds - A World Catalogue of Agents and their Target Weeds. (2nd Edit.) Commonw. Agric. Bur., Internat. Inst. Biol. Control, Imperial College, Silwood Park, Ascot, Berks, United Kingdom. 144 pp.
- Kasprzyk, M. J. and Bryant, G. L. 1989. Results of biological investigations from the Lower Virgin River vegetation management study. USDI-Bur. Reclam., Lower Colorado Region, Boulder City, NV, and Denver Office, Denver, CO. Rept. No. REC-ERC-89-2. 75 p.
- Keeler, J. E., et al. 1977. Mourning dove (Zenaidura macroura). (Chapter 9). pp. 274-298. *In*: Sanderson, G. C. (ed.), Management of migratory shore and upland game birds in North America. Internatl. Assoc. Fish and Wildlife Agencies, Washington, DC. 358 pp. ✓
- Kelleher, J. S. and Hulme, M. A. (eds.). 1984. Biological Control Programmes Against Insects and Weeds in Canada 1969-1980. Commonw. Agric. Bur., Farnham Royal, Slough, England. 410 pp.
- Kennedy, C. E. 1977. Wildlife conflicts in riparian management: Water. pp. 52-58. *In*: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.

- Kerpez, T. A. and Smith, N. S. 1987. Saltcedar control for wildlife habitat improvement in the southwestern United States. USDI Fish and Wildlife Serv. Resource Pub. 169. 16 pp.
- King, W., Hay, M. and Charbonneau, J. 1978. Valuation of riparian habitats. pp. 161-165. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Klingman, D. L. and Coulson, J. R. 1982. Guidelines for introducing foreign organisms into the United States for biological control of weeds. Weed Sci. 30:661-667.
- Knopf, F. L. and Olson, T. O. 1984. Naturalization of Russian-olive: Implications to Rocky Mountain wildlife. Wildlife Soc. Bull. 12(3):289-298.
- Knopf, F. L., Johnson, R. R., Rick, T., Samson, F. B. and Szaro, R. C. 1988. Conservation of riparian ecosystems in the United States. Wilson Bull. 100(2):272-284.
- Krulitz, L. M. 1979. Federal legal background for mitigation. pp. 19-26. In: Swanson, G. A. (Tech. coord.), The mitigation symposium: A national workshop on mitigating losses of fish and wildlife habitats, July 16-20, 1979, Fort Collins, CO. USDA For. Serv., Rocky Mtn. For. Range Expt. Sta., Ft. Collins, CO. Gen. Tech. Rept. RM-65. 696 pp.
- Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Kusler, J. A. 1978. Regulating critical riparian lands: A challenge in intergovernmental cooperation. pp. 332-335. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Larner, D. C., et al. 1974. Woody phreatophytes along the Colorado River from southeast Runnels County to the headwaters in Borden County, Texas. Texas Water Devel. Board Rept. 182. 19 pp.
- Lawson, L. L. 1950. The white-winged dove and mourning dove investigations. AZ Game & Fish Dept. Compl. Rept.
- Lee, C. H. 1912. An intensive study of the water resources of a part of Owens Valley. USDI-Geolog. Surv. Water-Supply Paper 294. 135 p.
- Lee, R. 1966. Effects of tent type enclosures on the microclimate and vaporization of plant cover. Oecol. Planta (Gauthier Villars) (Paris) 1: 301-326.

- Liesner, D. R. 1971. ~~Phytophagous insects of Tamarix spp. in New Mexico.~~  
M.S. Thesis, New Mexico St. Univ., Las Cruces. 73 p.
- Lowry, O. J. 1962a. Bureau of Reclamation, Region 5 (report), Minutes of Phreatophyte Subcommittee Meetings, Vol. II. p. 205, Attach. E.
- Lowry, O. J. 1962b. Bureau of Reclamation activities relating to phreatophytes calendar year 1962, Minutes of Phreatophyte Subcommittee Meetings, Vol. II. p. 247, Attach. D.
- Lowry, O. J. 1962c. Bureau of Reclamation (Report), Minutes of Phreatophyte Subcommittee Meetings, Vol. II. p. 159, Attach. C.
- Lowry, O. J. 1962d. Bureau of Reclamation, Minutes of Phreatophyte Subcommittee Meetings, Vol. II. p. 275, Attach. B.
- Lowry, O. J. 1966a. Mechanical and chemical control of phreatophytes. pp. 1-13. Amer. Conf. Civil Engr.
- Lowry, O. J. 1966b. Establishment, operation, and maintenance of phreatophyte control projects. pp. 1-12. USDI-Bur. Reclam.
- ✓ Lozovoi, A. I. 1961. Tamarisk and insect damage to it in dry regions of eastern Georgia. Vest. Tbilissk. Bot. Sada., Akad. Nauk. Gruzinsk SSR 67: 83-89.
- Lyles, L., Tatarko, J. and Dickerson, J. D. 1984. Windbreak effects on soil water and wheat yield. Trans. ASAE-American Soc. Agric. Engineers 27(1):69-72.
- Mace, A. C., Jr. 1971. Osmotic water stress: Mesophyll saturation deficit and transpiration rates of tamarisk. ~~Southw. Natur.~~ 16(1):117-120.
- Mace, A. C., Jr. and Thompson, J. R. 1969. Modifications and evaluations of the evapotranspiration tent. USDA-Forest Serv. Res. Paper RM-50. 16 pp.
- Mace, A. C., Jr., Tromble, J. M. and Croft, A. R. 1966. A study of the effects of phreatophyte removal on water, soil, and vegetation relations. Progress report for fiscal year 1965 and work schedule for fiscal year 1966, Annual Rept. No. 3. USDI-Bur. Reclam. and Univ. Ariz., Dept. Watershed Manage. 14 p. (mimeo)
- Mark, R. W. and Peterson, H. B. 1962. Tolerance of some trees and shrubs to saline conditions. Amer. Soc. Hort. Sci. 81:556-561.
- Martinez Lopez, A. 1986. Aspectos biologicos de la paloma de ala blanca (Zenaida asiatica) en la region norte del estado de sinaloa. Asso. Organizadores y Gias Cinegeticos, A.C. [in Spanish (mimeo)]. 44 pp.
- Mayeux, H. S., Jr. 1987. Application of herbicides on rangelands with a carpeted roller: Shrub density influences volume, dosage and rate. Weed Sci. 35:444-448.

- Mayeux, H. S., Jr., and Crane, R. A. 1983. The brush roller, an experimental herbicide applicator with potential for range weed and brush control. *Rangelands* 5(2):53-56.
- Mazzaccaro, A. P. 1980. A study of whitewing dove hunters in south Texas and the Republic of Mexico. Ph.D. Dissert. Texas A&M University. 176 pp.
- McCormick, J. F. 1978. Summary: A summary of the National Riparian Symposium: A proposal for a National Riparian Program. pp. 362-363. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- McDonald, C. C. and Hughes, G. H. 1968. Studies of consumptive use of water by phreatophytes and hydrophytes near Yuma, Arizona. USDI-Geolog. Surv. Prof. Paper 486-F. 24 pp.
- McGinnies, W. G. and Arnold, J. F. 1939. Relative water requirements of Arizona range plants. *Arizona Agric. Exp. Stn. Tech. Bull.* 80. pp. 165-246.
- McGuire, J. R. 1978. Position paper: A riparian policy for changing times. pp. 341-343. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- McNatt, R. 1978. Possible strategies for preservation of the San Pedro River riparian community. pp. 201-206. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Meinzer, O. E. 1927. Plants as indicators of ground water. USDI-Geolog. Surv. Water-Supply Paper 577. 95 pp.
- Merkel, D. L. and Hopkins, H. H. 1957. Life history of saltcedar (*Tamarix gallica* L.). *Kansas Acad. Sci.* 60(4):360-369.
- Mikus, B. 1989. Summary report on *Tamarix chinensis* Lour. at Organ Pipe Cactus National Monument. pp. 42-45. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Minckley, W. L. and Clark, T. O. 1984. Formation and destruction of a Gila River mesquite bosque community. *Desert Plant* 6(1):23-30.
- Morton, F. I. 1975. Estimating evaporation and transpiration from climatological observations. *J. Appl. Meteorol.* 14:448-497.

- Muckel, D. C. 1966. Phreatophytes -- Water use and potential water savings. J. Irriga. Drain Div., Proc. Amer. Soc. Civil. Engrs. 4: 27-34.
- Nawwar, M. A. M., Ishak, M. S., El Sherbieny, A. E. D. A. and Meshaal, S. A. 1977. Flavonoids of Reaumuria mucronata and Thymelaea hirsuta. Phytochem. 16:1319-1320.
- Neely, D. 1988. Valuation of landscape trees, shrubs and other plants. 7th Ed. Intl. Soc. Arboriculture, Urbana, IL. 50 pp.
- Neff, J. A. 1940. Range, population and game status of the western white-winged dove in Arizona. J. Wildlife Manage. 4:117-127.
- Neill, W. M. 1983. The tamarisk invasion of desert riparian areas. Educ. Found. Desert Protective Council., Inc. Educ. Bull. 83-4. 4 pp.
- Neill, W. M. 1989. Control of tamarisk by cut-stump herbicide treatments. pp. 91-98. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Oaks, W. R., Fenchel, G. A., Swenson, E. and Shrader, T. 1989. Selection and development of plant materials for use in southwest riparian zones. In: Practical Approaches to Riparian Resource Management: an Educational Workshop. Bur. Land Manage., Billings, MT. 192 p.
- Odum, E. P. 1978. Opening address: Ecological importance of the riparian zone. pp. 2-4. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.
- Ohmart, R. D. 1982. Past and present biotic communities of the Lower Colorado River mainstem and selected tributaries - Volume I, Davis Dam to Mexican Border. Center for Environmental Studies, Arizona State Univ., Tempe, AZ, for Bur. Reclam., Lower Colorado Reg. Boulder City, NV. 238 p.
- Ohmart, R. D., Deason, W. O. and Burke, C. 1977. A riparian case history: The Colorado River. pp. 35-47. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- O'Neal, R. J. and Waller, G. D. 1984. On the pollen harvest by the honey bee (Apis mellifera L.) near Tucson, Arizona (1976-1986). Desert Plants 6(2):81-109.
- PSIAC (Pacific Southwest Inter-Agency Committee). 1966a. Minutes of phreatophyte subcommittee meetings, Vol. 1, Jan. 1951 through Dec. 1959. 30 pp.

- PSIAC (Pacific Southwest Inter-Agency Committee). 1966b. Minutes of phreatophyte subcommittee meetings, Vol. II, Jan. 1960 through Dec. 1966. 30 pp.
- PSIAC (Pacific Southwest Inter-Agency Committee). 1970. Minutes of phreatophyte subcommittee meetings, Vol III, Jan. 1967 through Dec. 1970. 47 pp.
- Padgett, J. R. 1952. Root pruning makes athel (Tamarix aphylla) good wind-break. Texas Farm. Citricult. 29(6):12-13.
- Patton, D. R. 1977. Riparian research needs. pp. 80-82. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Pemberton, R. W. and Hoover, E. M. 1980. Insects associated with wild plants in Europe and the Middle East--Biological control of weeds surveys. USDA Misc. Pub. No. 1382. 33 pp.
- Petranka, J. W. and Holland, R. 1980. A quantitative analysis of bottomland communities in south-central Oklahoma. Southw. Natur. 25(2):207-214.
- Phillips, A. R., Marshall, J. and Monson, G. 1964. The birds of Arizona. Univ. Ariz. Press, Tucson, 220 pp.
- Pinkney, F. C. 1990. <sup>2</sup> ~~Revegetation and enhancement of riparian communities~~ <sup>along</sup> ~~Lower Colorado vegetation management study.~~ Rept., USDI-Bur. Reclam, Denver, CO. <sup>143</sup> 127 p. + Appendices A, B, C, D, E (Tot 187 p.)
- Potter, L. D. and Pattison, N. B. 1976. Shoreline ecology of Lake Powell. Lake Powell Res. Proj. Bull. No. 29. 235 pp.
- Powers, B. and Hamilton, K. C. 1961. Report on the revegetation of a cleared section of a floodway. Note: Agric. Expt. Stn., Univ. Arizona, Tucson, April 1961. 23 pp.
- Qaiser, M. 1976. Revision of the family Tamaricaceae from Pakistan. I. The genera Myricaria Desv. and Reaumuria Linn. Pak. J. Bot. 8(2):199-212.
- Qaiser, M. 1981. The genus Tamarix Linn. (Tamaricaceae) in Pakistan. Pak. J. Bot. 13(2):107-158.
- Qaiser, M. and S. I. Ali. 1978. Tamaricaria, a new genus of Tamaricaceae. Blumea 24:151-155.
- Quimby, P. C., Jr., and Campbell, C. J. A new look at the phreatophyte problem. [Date of draft: Nov. 12, 1971 - PRELIMINARY -NOT FOR PUBLIC RELEASE]. 24 pp.
- Quimby, P. C., Hollingsworth, E. B. and McDonald, R. L. 1977. Techniques for greenhouse evaluation of herbicides on saltcedar. Weed Sci. 25(1):1-4.

- Ramirez, P. Jr. 1986. Water development projects in the Rio Grande and this relationships to the Santa Ana and Rio Grande Valley national wildlife refuges. USDI Fish and Wildlife Serv. - Reg. 2, Corpus Christi. Report. 40 pp.
- Rantz, S. E. 1968. A suggested method for estimating evapotranspiration by native phreatophytes. Geological Survey Research. U.S. Geol. Surv. Prof. Paper 600-D, pp. D10-D12. 600-D. out 1/2  
29/6
- Read, R. A. 1964. Tree windbreaks for the central Great Plains. USDA Handbook. 250 pp.
- Rinne, J. N. 1985. Livestock grazing effects on southwestern streams: A complex research problem. pp. 295-299. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. Rocky Mtn. For. Range Expt. Sta. Tech. Rept. RM-120. Fort Collins, CO. 523 pp.
- Robbins, H. E. 1953. Salt cedar control and water conservation, soil and moisture conservation operations, Calrsbad, New Mexico, March 1, 1953. USDI-Bur. Reclam., Div. Operations and Maint., Reg. 5. 68 p. (mimeo)
- Robinson, T. W. 1958. Phreatophytes. U.S. Geol. Serv. Water Supply Paper 1423. 81 pp. ✓
- Robinson, T. W. 1962. General Hydrology Branch. pp. 17-23. In: Third Progress Report, Humboldt River Research Project, Nevada Dept. Conserv., Carson, City, NV. 35 p.
- Robinson, T. W. 1964. Phreatophyte research in the western states March 1959 to July 1964. U.S. Geol. Surv. Circ. 495. 31 pp.
- Robinson, T. W. 1965. Introduction, spread and areal extent of saltcedar Tamarix in the western states. USDI Geolog. Surv. Prof. Paper 491-A. 12 pp.
- Robinson, T. W. and Bowser, C. W. 1959. Buckeye project - water use by saltcedar. Prepared for 59-3 Phreatophyte Subcomm. Mtg. Pacific Southw. Inter-Agency Comm., Sept. 1959. 26 pp.
- Rorabaugh, J., Dunn, S., Ferrier, G. and Gould, G. 1989. An overview of Bureau of Reclamation riparian revegetation efforts on the Lower Colorado and Lower Gila Rivers, Arizona. Fourth Ann. Meet. Arizona Riparian Council, McNary, AZ, Sept. 22-23, 1989. (Abstract).
- Rowe, P. B. 1963. Streamflow increases after removing woodland-riparian vegetation from a southern California watershed. J. For. 61:365-370.
- ✓ Rowlands, P. G. 1989. History and treatment of the saltcedar problem in Death Valley National Monument. pp. 46-56. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.

Ruff, J. F., Skinner, M. M. and Dorratcague, D. E. 1973. Remote sensing study of salt cedar on the Pecos River near Roswell, New Mexico. Prepared for Bur. Reclam.-USDI, Denver, CO. CER72-73JFR-MMS24. 19 pp.

SCS-USDA. 1953. Grass variety test, project on the McMillan Delta area. USDA-Soil Conserv. Serv., Reg. Nursery Div., Albuquerque, NM. Unpubl. rept., pp. 60-65.

SCS-USDA. 1964. Grassland restoration Part II--Brush control. USDA-Soil Conserv. Serv., Temple, TX. 39 pp.

SCS-USDA. 1965. Grassland restoration Part III--Re-establishing forage plants. USDA-Soil Conserv. Serv., Temple, TX. 29 pp.

SCS-USDA. 1982. National List of Scientific Plant Names. Vol. 1. List of Plant Names. USDA-Soil Conserv. Serv. SCS-TP-159. 416 pp.

SCS-USDA. 1989. Dormant pole planting. USDA-Soil Conserv. Serv., Albuquerque, NM, Biol. Tech. Note. No. NM-35-190. 4 pp.

*Sanderson*

Sands, D. P. A. and K. L. S. Harley. 1981. Importance of geographic variation in agents selected for biological control of weeds. pp. 81-89. In: DelFosse, E. (ed.), Proc. V Intl. Symp. Biol. Control Weeds, Brisbane, Australia. July 1980. ✓

Saunders, G. B. 1968. Seven new white-winged doves from Mexico, Central America and southwestern United States. North American Fauna #65. U.S. Bur. Sport Fisheries and Wildlife, Washington, DC. 30 pp.

Sauriol, C. 1967. Saltcedar (Tamarix Pentandra) honey. Amer. Bee J. 107(6):219.

Scala, J. R. 1984. Recent vegetation changes and their relationship to beach soil dynamics along the Colorado River through Grand Canyon. Univ. Virginia M.S. Thesis. Charlottesville. Unpublished. 173 pp.

Schmidly, D. J. and Ditton, R. B. 1976. A survey and analysis of recreational and livestock impacts on the riparian zone of the Rio Grande in Big Bend National Park. Report prepared for Off. Natural Resources, Southw. Reg., Natl. Park Serv., Santa Fe, NM (contract no. CX70050442). 160 pp.

Schmidly, D. J. and Ditton, R. B. 1978. Relating human activities and biological resources in riparian habitats of western Texas. pp. 107-116. In: Johnson, R. R. and McCormick, F. J. (Tech. coord.), Proc. Symp. Strategies for protection and management of floodplain wetlands and other riparian ecosystems, Dec. 11-13, 1978, Callaway Gardens, GA. USDA For. Serv., Washington, DC. Gen. Tech. Rept. WO-12. 410 pp.

Schmidly, D. J., Ditton, R. B., Boer, W. J. and Graefe, A. R. 1976. Interrelationships among visitor usage, human impact, and the biotic resources of the riparian ecosystem in Big Bend National Park. Paper presented at First Conf. Scientific Research in the Natl. Parks, New Orleans, LA, November.

- Schultze, R. F. and Wilcox, G. I. 1985. Emergency measures for streambank stabilization: An evaluation. pp. 59-61. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. Rocky Mtn. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-120. 523 pp.
- Scifres, C. J. 1980. Brush management: Principles and practices for Texas and the Southwest. Texas A&M Univ. Press, College Station. 360 pp.
- Scobey, F. C. 1942. Survey of water-consuming areas. Part III, Sect. 2. The Pecos River Joint Investigation: Reports of the Participating Agencies. National Resources Planning Board. 407 pp.
- Scudday, J. R., Gallucci, T. L. and West, P. W. 1980. The status and ecology of the white-winged dove of Trans-Pecos Texas. US Fish and Wildl. Serv. Contr. No. 14-16-0008-2096. 118 pp.
- Sebenik, P. G. 1967. An evaluation of the enclosure effects of evapotranspiration tents on leaf temperatures of Tamarix pentandra. MS Thesis, Univ. Ariz., Tucson.
- Sebenik, P. G. and Thames J. L. 1967. Water consumption by phreatophytes. Progr. Agric. Ariz. 19(2):10-11.
- Shachori, A. Y., Stanhill, G. and Michaeli, A. 1962. The application of integrated research approach to the study of effects of different cover types on rainfall disposition in the Carmel Mountains, Israel. Symp. Methodology of Plant Eco-physiology, UNESCO Arid Zone Program, Institut de Botanique. Montpellier, France. 17 pp.
- Sharrow, D. 1989. Status of tamarisk and its control in Grand Canyon National Park. pp. 57-60. In: Künzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USDI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Shaw, H. 1961. Influence of salt cedar on white-winged doves in the Gila Valley. 9 pp.
- Shaw, H. and Jett, J. 1959. Mourning dove and white-winged dove nesting in the Gila River bottom between Gillespie Dam and the junction of the Salt and Gila Rivers, Maricopa County, Arizona. Ariz. Dept. Game & Fish Special Rept. Proj. W-53-R10, WP3, J2.
- ✓ Shrader, T. 1985. Response of saltcedar to selected soil-applied herbicides. pp. 347-349. 1985 Research Progress Rept., Proc. Western Soc. Weed Sci.
- Shrader, T. H. 1977. Selective management of phreatophytes for improved utilizations of natural flood-plain resources. Ground water salvage, Arizona, New Mexico, and Texas. Vol. 2. pp 16-44. In: Water Management for Irrigation and Drainage: Proc. Am. Soc. Civil Eng.

- Shrader, T., Perez, A., Oaks, W., Swenson, E., and Fenchel, G. 1989. Revegetation of riparian sites in central New Mexico. USDI-Bur. Reclamation., Upper Colorado Region, Rio Grande Proj., El Paso, TX. 4 p.
- Sisneros, D. 1990. Vegetation management study: Lower Colorado River. Appendix II. Herbicide analysis. USDI-Bur. Reclam., Denver Office. 65 p + 12 herbicide labels, application methods and FIFRAA exemptions.
- Spear, M. J. 1985. Position Paper: Activities and view of the U. S. Fish and Wildlife Service on riparian ecosystems. pp. 27-29. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. USDA-For. Serv., Rocky Mtn. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-120. 523 pp.
- Stamp, N. E. 1978. Breeding birds of riparian woodland in south-central Arizona. Condor 80: 64-71.
- Stevens, L. E., Brown, B. T., Simpson, J. M. and Johnson, R. R. 1977. The importance of riparian habitat to migrating birds. pp. 156-164. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Stevens, L. E. 1985. Invertebrate herbivore community dynamics on Tamarix chinensis Loureiro and Salix exigua Nuttall in the Grand Canyon, Arizona. Ph.D. Dissert., Northern Arizona Univ. 161 pp.
- Stevens, L. E. and Waring, G. L. 1985. The effects of prolonged flooding on the riparian plant community in Grand Canyon. pp. 81-86. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. USDA-For. Serv., Rocky Mtn. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-120. 523 pp.
- Sukopp, H. and Trautmann, W. 1981. Causes of the decline of threatened plants in the Federal Republic of Germany. pp. 113-116. In: Synge, H. (ed.), The Biological Aspects of Rare Plant Conservation. John Wiley and Sons, New York.
- Swank, W. G. 1952. Contribution to the knowledge of the life history and ecology of the mourning dove in Texas. Ph.D. Dissert., Texas A&M Univ. 157 pp.
- Swanson, G. A. (Tech. coord.). 1979. The mitigation symposium: A national workshop on mitigating losses of fish and wildlife habitats, July 16-20, 1979, Fort Collins, CO. USDA For. Serv., Rocky Mtn. For. Range Expt. Sta., Ft. Collins, CO. Gen. Tech. Rept. RM-65. 696 pp.

- Swenson, E. A. 1988. Progress in the understanding of how to reestablish native riparian plants in New Mexico. Sympos: Restoration, Creation, and Management of Wetlands and Riparian Ecosystems in the American West., Denver, CO. 10 p.
- Swenson, E. 1990. Plants being used in riparian revegetation in the Southwest. Presented at Manage. Riparian Ecosystems in the Southwest. New Mexico State Univ., Las Cruces. 1 p.
- Swenson, E. A. and Mullins, C. L. 1985. Revegetating riparian trees in southwestern floodplains. pp. 135-138. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. USDA-For. Serv., Rocky Mtn. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-120. 523 pp.
- Swenson, J. E., Hendricks, P. and Farjon, A. 1982. Arrival and occurrence of Tamarix chinensis (Tamarisk) along the Yellowstone River in Treasure and Rosebud Counties, Montana. Proc. Mont. Acad. Sci. 41:67-70.
- Szaro, R. C. 1981. Bird population responses to converting chaparral to grassland and riparian habitats. Southw. Natur. 26(3):251-256.
- Szaro, R. C. and DeBano, L. F. 1985. The effects of streamflow modification on the development of a riparian system. pp. 211-215. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), Riparian ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. USDA-For. Serv., Rocky Mtn. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-120. 523 pp.
- Szaro, R. C. and Rinne, J. N. 1988. Ecosystem approach to management of southwestern riparian communities. pp. 502-511. In: Trans. 53rd North Amer. Wildlife and Natural Resources Conf.
- Takhtajan, A. 1980. Outline of the classification of flowering plants (Magnoliophyta). Bot. Rev. 46:225-359.
- Taylor, J. 1987. Imazapyr (Arsenal) use and performance on saltcedar (Tamarix pentandra), willow (Salix and Baccharis spp.) and phragmites (Phragmites communis) at the Bosque del Apache NWR. USDI-Fish and Wildlife Service. 15 p.
- Theis, C. V. 1951. Comparative consumptive use of water by salt cedar and replacement vegetation. Appendix IV, pp. 1-11. In: H. B. Elmendorf, et al., Report to Salt Cedar Interagency Council. Salt Cedar Interagency Task Force, New Mexico. Albuquerque, Feb. 1, 1951.

- Thomas, L., Kitchell, K. and Graham, T. 1989. Summary of tamarisk control efforts in Canyonlands and Arches National Parks and Natural Bridges National Monument. pp. 61-66. In: Kunzmann, M. R., Johnson, R. R. and Bennett, P. S. (Tech. coord.), Proc. Tamarisk Conf. Sept. 2-3, 1987, Univ. Arizona, Tucson, AZ. USOI-Natl. Park Serv. Natl. Park. Resources Studies Unit Spec. Rept. No. 9. 141 pp.
- Thompson, C. B. 1956. Attachment E, Minutes of 55-2 Meeting, P.S.I.A.C., Phreatophyte Subcommittee. p. 158, Item 6.
- Thomsen, B. W. and Schumann, H. H. 1968. Water resources of the Sycamore Creek watershed, Maricopa County, Arizona. U.S. Geol. Surv. Water-Supply Paper 1861. 53 pp.
- Thorne, R. F. 1976. A phylogenetic classification of the Angiospermae. *Evol. Biol.* 9:35-106.
- Thorne, R. F. 1983. Proposed new realignments in the angiosperms. *Nordic J. Bot.* 3:85-117.
- Thornthwaite, C. W. 1948. An approach toward a rational classification of climate. *Geog. Rev.* 38:55-94.
- Timmons, F. L. 1963. Research in the control of phreatophytes. Presented at Soil Conservation Service Hydraulic Engr. Mtg., New York City.
- Tomanek, G. W. and Ziegler, R. L. 1962. Ecological studies of salt cedar. Fort Hays State Coll., Hays. 128 pp.
- Tomlinson, R. E. 1988. Hunter declaration at border ports of doves and pigeons bogged in Mexcio during the 1987-88 hunting season. 11 pp.
- Turner, R. M. 1974. Quantitative and historical evidence of vegetation changes along the Upper Gila River, Arizona. USOI Geolog. Surv. Prof. Paper 655-H. 20 pp.
- Turner, R. M. and Karpiscak M. M. 1980. Recent vegetation changes along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona. USOI Geolog. Surv. Prof. Paper 1132. 24 pp.
- Turner, S. F. and Halpenny, L. C. 1941. Ground-water inventory in the upper Gila River Valley, New Mexico and Arizona: Scope of investigation and methods used. *Trans. Amer. Geophysical Union* 22(3):738-744.
- van Hylckama, T. E. A. 1960. Measuring water use by saltcedar. Proc. Arizona Watershed Symposium.
- van Hylckama, T. E. A. 1966. Evaporation from vegetated and fallow soils. *Water Resour. Res.* 2(1):99-103.
- van Hylckama, T. E. A. 1968a. Effect of soil salinity on the loss of water from vegetated and fallow soil. pp. 635-643. In: Symp. on water in the unsaturated zone, June 19-25, 1966, Wageningen, The Neth. Int. Assoc. Sci. Hydrol. (Gentbrugge, Belgium) (mimeo) Vol. 83.

- van Hylckama, T. E. A. 1968b. ~~Water level fluctuations in evapotranspiro-~~  
meters. Water Resour. Res. 4: 761-768.
- van Hylckama, T. E. A. 1969. Photosynthesis and water use by saltcedar. Bull. Internatl. Assoc. Scientific Hydrology XIV(1):71-83.
- van Hylckama, T. E. A. 1970a. Water use by salt cedar. Water Resources Res. 6(3):728-735.
- van Hylckama, T. E. A. 1970b. Winds over saltcedar. Agr. Meteorol. 7(3): 217-233.
- van Hylckama, T. E. A. 1974. Water use by saltcedar as measured by the water budget method. US Geolog. Surv. Profess. Paper 491-E. 30 pp.
- van Hylckama, T. E. A. 1980a. Weather and evapotranspiration studies in a saltcedar thicket, Arizona. US Geolog. Surv. Profess. Paper 491-F. 78 pp. ✓
- van Hylckama, T. E. A. 1980b. Lysimeters and evapotranspirometers. pp. 161-166. In: Halasi-Kun, G. J. (Ed.), Pollution and water resources. Columbia University Seminar Series, Vol. XIII, Part 2. Pergamon Press.
- van Hylckama, T. E. A. 1980c. Phreatophytes. pp. 179-182. In: Halasi-Kun, G. J. (Ed.), Pollution and water resources, Vol. XIII, Part 2. Columbia University Seminar Series.
- Viers, C. E., Jr. 1970. The relationship of calling behavior of white-winged doves to population and production in southern Arizona. Ph.D. Dissert. Univ. Arizona. 47 pp.
- Waggener, G. 1974-88. Migratory shore and game bird research and surveys: White-winged dove. Fed. Aid Proj., Texas Parks & Wildlife Dept., Austin. (various Annual Performance Reports).
- Waisel, Y. 1961a. Ecological studies on Tamarix aphylla (L.) Karst I-II. Phytol 15(1):7-28.
- ✓ Waisel, Y. 1961b. Ecological studies on Tamarix aphylla (L.) Karst III: The salt economy. Plant Soil 13:356-364. ✓
- Waisel, Y. 1972. Biology of Halophytes. Academic Press, New York and London. 379 pp.
- Waller, G. D. and Schmalzel, R. 1976. Beekeeping in Arizona. Gleanings in Bee Culture, May 1976. 3 p. ✓
- Walter, H., Harnickell, E. and Mueller-Dombois, D. 1975. Climate-diagram maps of the individual continents and the ecological climatic regions of the earth. Springer-Verlag, NY. 36 p + maps.
- Wapshere, A. J. 1974. A strategy for evaluating the safety of organisms for biological weed control. Ann. Applied Biol. 77:201-211. ✓

- Wapshere, A. J. 1975. A protocol for programmes for biological control of weeds. PANS 21:295-303. ✓
- Wapshere, A. J. 1981. Recent thoughts on exploration and discovery for biological control of weeds. pp. 75-79. In Delfosse, E. S. (ed.), Proc. Fifth Intl. Symp. Biol. Control Weeds, Brisbane, Australia, July 22-29, 1980. 649 pp. ✓
- Wapshere, A. J. 1985. Effectiveness of biological control agents for weeds: Present quandaries. Agric. Ecosystems Environ. 13:261-280.
- Warren, D. K. and Turner, R. M. 1975. Saltcedar (Tamarix chinensis) seed production, seedling establishment and response to inundation. J. Ariz. Acad. Sci. 10(3):135-144.
- Warren, P. L. and Schwalbe, C. R. 1985. Herpetofauna in riparian habitats along the Colorado River in Grand Canyon. pp. 347-354. In: Johnson, R. R., Ziebell, C. D., Patton, D. R., Ffolliott, P. F. and Hamre, R. H. (Tech. coord.), First North American Riparian Conf, April 16-18, 1985, Tucson, AZ. USDA-For. Serv., Rocky Mtn. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-120. 523 pp.
- Watts, J. G., Liesner, D. R. and Lindsey, D. L. 1977. Saltcedar: A potential target for biological control. Bull. New Mexico Agr. Exp. Stn. 650. 28 pp.
- Wauer, R. H. 1977. Significance of Rio Grande riparian systems upon the avifauna. pp. 165-174. In: Johnson, R. R. and Jones, D. A. (Tech. coord.), Importance, preservation and management of riparian habitat: A symposium. July 9, 1977, Tucson, AZ. USDA For. Serv., Rocky Mt. For. Range Expt. Sta., Fort Collins, CO. Gen. Tech. Rept. RM-43. 217 pp.
- Webb, J. W. and Dodd, J. D. 1981. Tree and shrub establishment and survival on sandy dredged material. Southw. Natur. 26(4):345-352.
- Webb, P. M. 1967. Dove management information. Completion report W-53-R-17, WP3, J2. Arizona Dept. Game and Fish, Phoenix.
- Weeks, E. P., Weaver, H. L., Campbell, G. S. and Tanner, B. D. 1987. Water use by saltcedar and by replacement vegetation in the Pecos River floodplain between Acme and Artesia, New Mexico. U.S. Geolog. Surv. Prof. Paper 491-G. U.S. Govt. Print. Off., Washington, DC. 33 pp. ✓
- Wetmore, A. 1920. Observations on the habits of white-winged doves. Condor 22(4):140-146.
- Whalen, M. A. 1980. A systematic review of the New World species of Frankenia (Frankeniaceae). Ph.D. Disser., Univ. Texas, Austin. 421 p.
- Whalen, M. A. 1987. Systematics of Frankenia (Frankeniaceae) in North and South America. Syst. Bot. Monogr. 17:1-93.

- White, R. J. and Brynildson, O. M. 1967. Guidelines for management of trout stream habitat in Wisconsin. Tech. Bull. 39. Dept. Nat. Res. Madison, WI.
- White, W. N. 1932. Contributions to the hydrology of the United States. A method of estimating ground-water supplies based on discharge by plants and evaporation from soil: Results of investigations in Escalante Valley, Utah. USDI-Geolog. Surv. Water Sup. Paper 659. 105 p.
- Wiedemann, H. T. and Cross, B. T. 1978. Water inundation for control of saltcedar along the periphery of lakes. Proc. South Weed Sci. Soc. 31: 229.
- Wigal, D. D. 1973. A survey of the nesting habitats of the white-winged dove in Arizona. Ariz. Dept. Game and Fish Spec. Rept. 2. pp. 1-37.
- Wilkinson, R. E. 1966a. Reproduction of saltcedar by cuttings. Weeds 14(2):173-174.
- Wilkinson, R. E. 1966b. Adventitious shoots on saltcedar roots. Bot. Gaz. 127(23):103-104.
- Wilkinson, R. E. 1966c. Seasonal development of anatomical structures of saltcedar foliage. Bot. Gaz. 127(4):231-234.
- Wilkinson, R. E. 1966d. Vegetative response of saltcedar (Tamarix pentandra Pall.) to photoperiod. Plant Physiol. 41:271-276.
- Wilkinson, R. E. 1972. Water stress in salt cedar. Bot. Gaz. 133(1):73-77.
- Wright, H. A. and A. W. Bailey. 1982. Fire ecology: United States and Southern Canada. John Wiley and Sons, NY. 501 pp.
- Yonker, G. L. and Anderson, C. W. 1986. Mapping methods and vegetation changes along the Lower Colorado River between Davis Dam and the border with Mexico. USDI-Bur. Reclam., Lower Colorado Region, Boulder City, NV, Contract No. 6-CS-30-03800. 22 p. + Appendix and 21 maps.
- York, J. C. 1985. Dormant stub planting techniques. pp. 513-514. In: Riparian Ecosystems and their management: Reconciling conflicting uses. First North American Riparian Conf., Tucson, AZ.
- York, J.C. 1986. Dormant stock planting for channel stabilization. USDA-SCS Biology Note No. 22, Phoenix, AZ. 4 p.
- Young, A. A. and Blaney, H. F. 1942. Use of water by native vegetation. Calif. State Div. of Water Resources Bull. 50 [Sacramento, CA]. 154 pp.
- ✓ Zocchi, R. 1971. Contributo Alla Conoscenza Dell'Entomofauna Delle Tamerici in Italia. Redia 52: 31-129.
- Zwölfer, H. and Harris, P. 1971. Host specificity determination of insects for biological control of weeds. Annu. Rev. Entomol. 16:159-178.

NATIONAL AGRICULTURAL LIBRARY



1023018902